

Transactions of the Royal Society of South Australia Incorporated

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TRANSACTIONS OF THE

**ROYAL SOCIETY
OF SOUTH AUSTRALIA**

INCORPORATED

VOL. 120, PART 1

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INLAND-WATER CALANOID COPEPODS OF KANGAROO, KING AND FLINDERS ISLANDS: BIOGEOGRAPHY AND ECOLOGY

*By I. A. E. BAYLY**

Summary

Bayly, I. A. E. (1996) Inland-water calanoid copepods of Kangaroo, King and Flinders Islands: Biogeography and Ecology. Trans. R. Soc. S. Aust. 120(1), 1-6, 31 May, 1996.

Calanoid copepod identifications are provided for samples from 16 localities on Kangaroo Island, 18 on King Island and 11 on Flinders Island. The number of species found was five, three and seven, respectively. Conductivity data are given for most localities. Species richness in relation to land area is tabulated and discussed. *Boeckella major* is recorded from South Australian territory for the first time. The occurrence of *Hemiboeckella searli* in temporary pools and amongst dense macrophytes in lakes may be due to the absence of predators in young pools and the difficulty encountered by predators in searching dense weed-beds in lakes. The disjunct distribution of *Calamoecia gibbosa* is explicable on the basis of east to west dispersal along a lowland plain during the Pleistocene when sea levels were low, followed by marine inundation.

Key Words: Copepoda, Calanoida, biogeography, ecology.

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KEY WORDS: Copepoda, Calanoida, biogeography, ecology.

Introduction

Following the glacial (and aridity) maximum that occurred in the Late Pleistocene at about 18 ka B.P., deglaciation, and the consequent rise in sea level (Chappell 1978; Galloway & Kemp 1981), converted several areas of land along the southern margin of the Australian continent into islands. The nature and fate of the samples of the fauna of greater Australia provided by these islands is a matter of considerable interest. Rawlinson (1974) studied this issue with reference to the reptiles of Bass Strait islands and Tasmania and showed that a whole series of islands in Bass Strait and off South Australia became isolated during the period 16.5 - 6.3 ka B.P.

Despite their small size and the ability of many of them to produce desiccation-resistant eggs, freshwater calanoid copepods are widely acknowledged to exhibit poor dispersal ability (Bayly & Maly 1991; Bănărescu 1990; Bayly 1995). As a consequence, the biogeography of calanoid copepods is of considerable interest, with dispersal playing a smaller role than has been supposed by the numerous workers who simplistically equate the possession of resting eggs with good powers of dispersal (Bayly & Morton 1978).

This paper aims to examine the relationship of the calanoid fauna of three offshore islands (Fig. 1) with that of mainland Australia and Tasmania and to consider the role of historical and ecological factors in observed differences and similarities.

Methods

Each body of water was thoroughly sampled with a zooplankton net of mesh size 150 μm . Collections were preserved in 10% formalin. Conductivity of a water sample taken from the field in a polyethylene bottle was determined in the laboratory with a Radiometer CDM2e conductivity meter. Where the K_{25} exceeded 5.0 mS cm^{-1} , the conductivity value was converted to a salinity value using the method of Williams (1986). For the King Island localities, pH was measured with a Metrohm E599 portable pH-meter.

With two exceptions, the Flinders Island localities were sampled by the author alone at various times between 1985 - 1988, and by the author working with a limnological team from 10-12 February 1993. The King Island samples, with one exception, were taken by a team of workers including the author during the period 2-5 December 1991. With two exceptions, the Kangaroo Island samples were collected by the author alone during the period 26 June - 3 July 1994.

Results

Physico-chemical and biological results are summarised in Tables 1 - 3. Five calanoid species were recorded from Kangaroo Island, with only two species, *Boeckella triarticulata* and *Calamoecia clitellata*, occurring at those localities with a salinity of 3.3 g l^{-1} or more. At the less saline localities, *B. major* was restricted to temporary waters. Only three species were found on King Island, and one of these, *B. pseudochelae*, occurred in the sole temporary water body that was sampled. *C. tasmanica* was the only species found in waters with a recorded pH of less than 6.0. None of the King Island waters included in the survey was saline. Seven species were recorded from Flinders Island with *C. tasmanica* most common. *B. symmetrica* was the only species common to all three islands.

* Department of Ecology and Evolutionary Biology, Monash University Clayton Vic. 3168.
Current address: 114 Belgrave Hallam Road Belgrave South Vic. 3160.

TABLE 1. Occurrence of calanoid copepods on Kangaroo Island.

Locality	Sampling date	Permanency ^a	Conductivity [K ₂₅] (mS cm ⁻¹)	Salinity (g l ⁻¹)	Bm	Species ^b			Ca	Cc
						Bs	Bt			
Dam 1 near Penneshaw ^c	20.viii.1991	P				x			x	
Dam 2 near Penneshaw ^c	20.viii.1991	P				x				
Waterhole edge Edwards Lagoon	30.vi.1994	T	0.21		x	x				
Pond Roper Road	1.vii.1994	T	0.22		x	x				
Lake at Karatta	28.vi.1994	SP	0.31			x			x	
Pond nr rush Lagoon	27.vi.1994	T	0.44		x					
Pond south end Roper Road	1.vii.1994	SP	1.23			x				
Ditch east Kingscote Airport	27.vi.1994	T	1.71		x	x				
Small Grassdale Lagoon	28.vi.1994	SP	3.00			x				
Big Grassdale Lagoon	28.vi.1994	P	3.65			x				
Kaiwarra Cottage Pond	2.vii.1994	T	5.8	3.2	x	x				
Duck Lagoon	1.vii.1994	P	6.0	3.3			x			
Discovery Lagoon	27.vi.1994	T	9.0	5.1			x			
Lake Ada	3.vii.1994	P	12.8	7.5			x			
Murray Lagoon	3.vii.1994	P	15.3	9.1			x			
White Lagoon	27.vi.1994	SP	75.3	51.3						x

a. P = permanent; SP = semi-permanent; T = temporary

b. Bm - *Boeckella major* Searle; Bs = *B. symmetrica* Sars; Bt = *B. triarticulata* (Thomson);

Ca = *Calamoecia ampulla* (Searle); Cc = *C. clitellata* Bayly.

c. collected by N. Frick

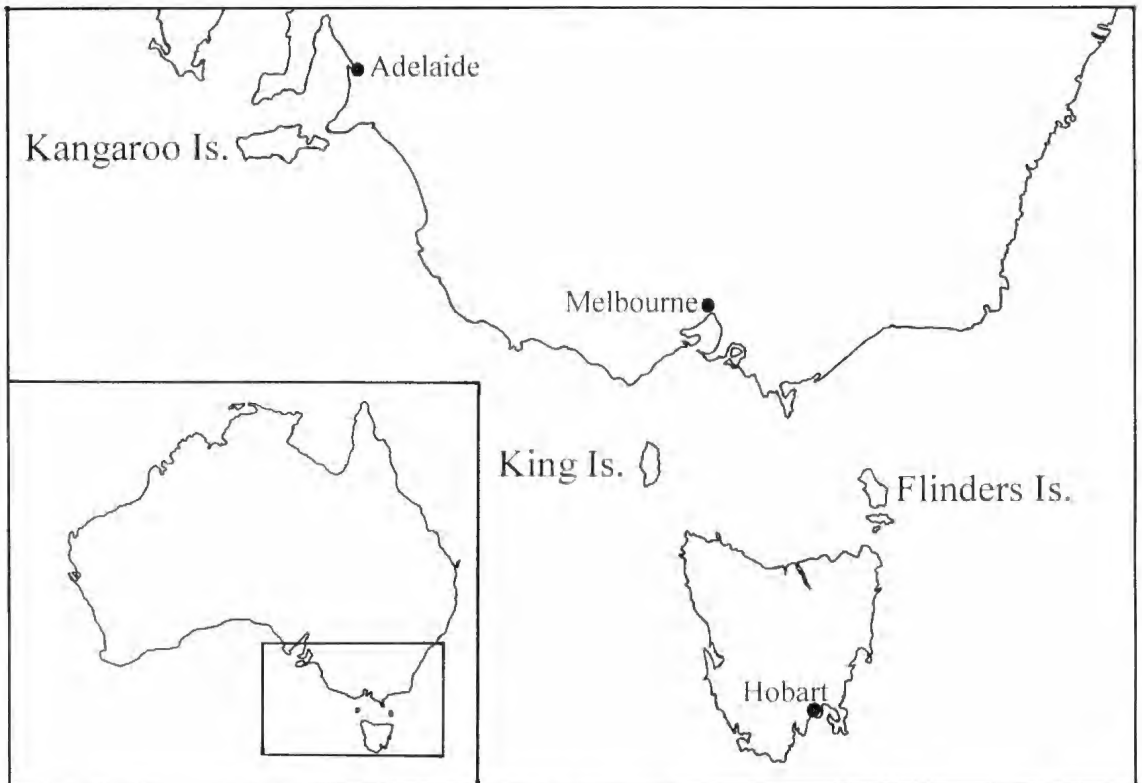


Fig. 1. Map showing location of Kangaroo, King and Flinders Islands.

TABLE 2. Occurrence of calanoid copepods on King Island.

Locality	Sampling date	Permanency ^a	Conductivity [K ₂₅] (mS cm ⁻¹)	pH	Species ^b		
					Bp	Bs	Ct
Pool nr Currie ^c	8.xi.1963	T	-	-	x		
Meatsafe Lagoon	5.xii.1991	P	0.56	3.8			x
Dead Sea	2.xii.1991	P	0.56	4.7			x
Lake Martha Lavinia	3.xii.1991	P	0.75	5.2			x
Seal Rock Lagoon (North)	4.xii.1991	P	0.96	7.9		x	
Pearshape Lagoon	2.xii.1991	P	1.04	7.8		x	
Lake nr Surprise Bay Homestead	4.xii.1991	SP	1.10	7.4		x	
Lake opp. Pearshape Lagoon	2.xii.1991	P	1.13	8.2		x	
Pennys Lagoon	3.xii.1991	P	1.15	7.7		x	x
Granite Lagoon	5.xii.1991	P	1.26	6.4		x	
Pioneer Lagoon	4.xii.1991	P	1.46	7.8		x	
Lake btn Denbys & Pioneer Lagoon	2.xii.1991	P	1.47	7.2		x	
Denbys Lagoon	2.xii.1991	P	1.57	6.6		x	x
Lake east end Pioneer Lagoon	4.xii.1991	SP	1.80	8.5		x	
Seal Rock Lagoon (Middle)	4.xii.1991	SP	1.90	7.5		x	x
Cask Lake	3.xii.1991	P	1.96	8.2		x	
Lake Wickham	3.xii.1991	SP	2.15	8.9		x	
Lake Flannigan	3.xii.1991	SP	2.28	9.9		x	

a. P = permanent; SP = semi-permanent; T = temporary

b. Bp = *Boeckella pseudocheilae* Searle; Bs = *B. symmetrica* Sars; Ct = *Calamoecia tasmanica* (Smith);

c. collected by M. J. Littlejohn.

TABLE 3. Occurrence of calanoid copepods on Flinders Island.

Locality	Sampling date	Permanency ^a	Conductivity [K ₂₅] (mS cm ⁻¹)	Salinity (g l ⁻¹)	Species ^b						
					Bm	Bp	Bs	Bt	Hs	Cg	Ct
Brodiess Lagoon ^c	May 1962	T						x			
Scotts Lagoon ^c	May 1962	T								x	
Pond nr Sticks Lagoon	15.v.1985	T									x
Pond (1) nr Killiecrankie	5.vi.1988	T			x						
Pond (2) nr Killiecrankie	5.vi.1988	T					x				
Reedy Lagoon	9.vi.1988	P				x				x	
Shag Lagoon	12.ii.1993	T	1.7								x
Lake btn N & S Patriarchs	19.v.1985	SP	2.2						x		x
Small lake (1)											
nr Singleton's Lagoon	10.ii.1993	T	2.4								x
Small lake (2)											
nr Singleton's Lagoon	10.ii.1993	T	5.1	2.7							x
Sticks Lagoon	15.v.1985	T	12.3	7.1				x			

a. P = permanent; SP = semi-permanent; T = temporary

b. Bm = *Boeckella major* Searle; Bp = *B. propinqua* Sars; Bs = *B. symmetrica* Sars; Bt = *B. triarticulata* (Thomson); Hs = *Hemiboeckella searli* Sars; Cg = *Calamoecia gibbosa* (Brehm); Ct = *C. tasmanica* (Smith).

c. collected by W. D. Williams

Discussion

It is probably not valid on the basis of Tables 1-3 to attempt straightforward and unqualified comparisons between the faunas of any two of the three islands; complications could conceivably arise from differences in season of sampling, year of sampling, ratio of permanent and semi-permanent to temporary waters and number of localities sampled. However, it is important to note that in Australasia, calanoid copepods are nearly always present perennially in permanent standing waters (a few glacial or high altitude lakes

are the only exceptions) despite wide fluctuations in population density (Bayly & Williams 1973). In any large sample at least some males and egg- or spermatophore-bearing females are present and the species determinable. This means that yearly or seasonal differences in sampling dates should not unduly influence the assessment of the fauna of the permanent waters. This leaves a residuum of problems for comparisons which, however, are not so great as to preclude the examination of a number of general features and trends.

The much cited island biogeography theory of

MacArthur & Wilson (1967) would predict that a positive correlation should exist between the number of species found within a discrete area and the size of that area. With respect to non-marine calanoids in the Australasian region, Table 4 indicates that across the whole spectrum of six land masses there is only a very rough correlation of the sort predicted. Several anomalies call for consideration and explanation.

King Island and Flinders Island differ only slightly in area but the former apparently has less than half the number of species found on the latter. This difference, if it is not an artefact, is difficult to explain but it may be significant that native habitat destruction, including the removal of vegetation, has proceeded to a greater extent on King Island than Flinders Island.

Kangaroo Island is about three and a half times larger than Flinders Island but has fewer calanoids (if the halobiont species *C. rhinellatus* is omitted it has only four species). It is difficult nowadays to find a large natural body of fresh water on Kangaroo Island. Extensive vegetation removal in the period 1945–1955 and the consequent rise in water tables and mobilisation of salt has resulted in the salinisation of several lowland lakes that were formerly fresh. Murray Lagoon originally contained fresh water but today it is saline (salinity 9.1 g l⁻¹ on 3 July 1994; Table 1). Several of the lakes on Kangaroo Island visited during the winter of 1994 were found to be highly saline and were not sampled for that reason. Half of the natural fresh waters that were located were very small and temporary in character. It is conceivable that species like *Calamoecia gibbosa* and *C. tasmanica*, which occur in south-eastern and south-western Australia and typically inhabit permanent fresh waters, no longer occur on Kangaroo Island as a result of recent salinisation.

New Zealand is about four times larger than Tasmania but has fewer calanoids. However, during the Oligocene, some two-thirds of the area of modern New Zealand was covered by sea (Stevens 1980).

Boeckella symmetrica, which occurred on all three islands, and *B. triarticulata*, which was found on Kangaroo and Flinders Islands, are both common and

widely distributed species (Bayly 1992a). The occurrence of *B. propinqua* on Flinders Island only (Table 3) is consistent with the existing evidence that, within Australia, this species is restricted to the far eastern fringe of the continent; previous Australian records are from the east coast of Tasmania and coastal New South Wales. *B. major* (Kangaroo and Flinders Islands; Tables 1 and 3) is characteristic of temporary waters and has been recorded previously from New South Wales, Victoria and Tasmania (Bayly 1992a). The present record from Kangaroo Island is the first from South Australian territory but it is likely that this merely reflects a lack of investigation in this State of the copepods of temporary ponds and pools. *R. pseudochelae* (King Island; Table 2) is another temporary water specialist previously noted from southern New South Wales, Victoria and Tasmania. *Calamoecia tasmanica* (King and Flinders Islands) and *C. ampulla* (Kangaroo Island) are widely distributed species known from south-eastern and south-western Australia (Bayly 1992a).

Hemiboeckella searli typically occurs in temporary ponds and pools, but, as with the present record from Flinders Island (Table 3), it also occurs in littoral weed beds in permanent or semi-permanent waters. This commonality of occurrence is not as incongruous as it first appears. Water permeating dense vegetation in the littoral region of a permanent lake has an ecological similarity to that in a shallow, temporary pool (including those entirely devoid of vegetation) that is not commonly appreciated namely, the exclusion of predators. It is well appreciated that, in a newly formed pool, flying insect predators such as notonectids may take some time to arrive and, until this occurs, the habitat may be largely predator-free. The fact that *Hemiboeckella* characteristically occurs very early in pool successions (Bayly 1992b) suggests a high degree of predator susceptibility. However, as pointed out by Connell (1975) some prey species have evolved the ability to live in refuges that the predator cannot invade because the habitat structure is too difficult to search. It is presumably for this reason that dense littoral vegetation offers *H. searli* a refuge from limnetic fish and insect predators in lakes. *H. searli* is widely distributed, occurring in south-eastern and south-western Australia.

Calamoecia gibbosa has the most intriguing distribution of all the Australian freshwater calanoids; it occurs in Tasmania, on Flinders Island, along the coastal fringe of south-eastern South Australia between Mt Gambier and Salt Creek and on two granite outcrops near Balladonia in Western Australia (Bayly 1984, 1992a). A previously unpublished record is from near Mt Rough to the south-east of Salt Creek in South Australia. The two Western Australian populations were treated (Bayly 1979, 1992a) as belonging to a separate subspecies from the eastern form.

TABLE 4. Land area and species richness

Name of land mass	Area (km ²)	Number of calanoid species ^a
King Island	1,200	3
Flinders Island	1,330	7
Kangaroo Island	4,400	5
Tasmania	67,800	15
New Zealand	269,000	10
Australia	7,682,000	33

a. Belonging to the family Centropagidae and restricted to the genera *Boeckella*, *Hemiboeckella* and *Calamoecia*.

The most reasonable explanation for current disjunctions in the distribution of *C. gibbosa* is that, at the time of one of the three glacial maxima during the Late Pleistocene (Chappell 1978), probably the last one at 18 ka B.P., it was continuously distributed along a coastal lowland plain to the south of the present southern coastline of Australia. It may be supposed to have extended from eastern Bass Strait to the western limit of the Great Australian Bight (cf. Nelson 1981, fig. 2). A subsequent rise in sea level of more than 100 m (Chappell 1978) would then have been responsible for the present day disjunctions. The morphological evidence suggests that the Western Australian form is a derived rather than ancestral form. Thus it is proposed that, some time within the Wisconsin glaciation when sea levels had been lowered by about 100 m, gradual east to west dispersal of *C. gibbosa* occurred along a broad coastal plain that is now submerged. This proposal of east to west dispersal, followed by subspeciation in the west as a result of vicariant isolation, parallels the pattern of speciation in Western Australian frogs first proposed by Main *et al.* (1958) and subsequently adopted by Main (1968) and Littlejohn (1981). It should be noted, however, that more recent molecular data on frogs is said not to support multiple east to west invasions during the Pleistocene as being the explanation for speciation in Western Australia (Roberts & Maxson 1985).

If we accept submergence of the southern plain as the explanation for the disjunctions in the distribution of *C. gibbosa*, then three explanations may be offered for the apparent absence of this species from Kangaroo Island and King Island. First, the species does occur on these islands but the present samplings were not intensive enough to reveal it. Second, *C. gibbosa* was originally present on these islands but subsequent ecological changes (e.g. salinisation on Kangaroo Island) have brought about its local extinction. Third, although the original distribution of *C. gibbosa* along the now submerged plain was continuous in a broad sense, it was nevertheless somewhat patchy, and the persistent land samples provided by these two islands were not sufficiently large to include this calanoid.

Acknowledgments

During the fieldwork on King Island in December 1991, I was accompanied by Russell Shiel, Grace and Peter Tyler and Robert Walsh. On Flinders Island in February 1993 I had the company of Peter Kew, Colin Magilton, Russell Shiel, Peter Tyler and Robert Walsh. I thank all of these people for their companionship and assistance. The field work carried out on King Island and Flinders Island was supported by a National Estate Grant to P. A. Tyler. Additionally, Monash University contributed funds towards the King Island expedition.

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THERMOLUMINESCENCE DATING OF VOLCANIC ACTIVITY AT MOUNT GAMBIER, SOUTH AUSTRALIA

By G. B. ROBERTSON, J. R. PRESCOTT* & J. T. HUTTON†*

Summary

Robertson, G. B., Prescott, J. R. & Hutton, J. T. (1996) Thermoluminescence dating of volcanic activity at Mount Gambier, South Australia. *Trans. R. Soc. S. Aust.* 120(1), 7-12, 31 May, 1996.

There are several products of volcanic activity which have the potential to be dated by thermoluminescence (TL) such as lava, volcanic ash and glass, and layers of tuff and sand lying beneath a lava flow. One of the most important factors in obtaining a reliable date is the search for materials which have been sufficiently heated or bleached by sunlight to reset the TL clock at the time of the eruption. We report the investigation of a number of such materials from the Mount Gambier volcanic complex. A date of 4.2 ± 0.5 ka was obtained for the baked tuff underlying the lava flow at Valley Lake. Other results suggest that an additional event may have occurred about 7 ka ago (i.e. during the Holocene). Lava and glass samples from nearby sites had insufficient amounts of datable quartz and other samples had not been sufficiently heated but the investigation has been valuable in providing evidence of the extent to which TL dating can be applied to a context like the one at Mount Gambier.

Key Words: Thermoluminescence dating, volcanism, Holocene, Mount Gambier.

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KEY WORDS: Thermoluminescence dating, volcanism, Holocene, Mount Gambier.

Introduction

There has been a number of attempts at determining the sequence of events and the time scale involved in the formation of the volcanic complex at Mount Gambier in South Australia's South-east. The findings indicate that the volcano as we see it today is the result of a very complicated series of events, possibly spread over several thousand years. The earliest radiocarbon dates obtained by Fergusson and Rafter (1957) indicated two main periods of eruption, one at 4700 ± 70 years B.P., the other at 1410 ± 90 years B.P. These dates were incorporated into a geological history of the eruptions by Sheard (1978). Subsequently Blackburn *et al.* (1982) concluded that the most likely C-14 age was about 4 thousand years (ka) although charcoal samples were found covering the range 3.5 to 8 ka. Barton and McElhinney (1980) suggested that Mount Gambier must pre-date 5-6 ka B.P. Recently published work by Leaney *et al.* (1995) on C-14 in the inorganic and organic carbon fractions of Blue Lake sediment cores point to volcanic activity at about 7 ka. On the other hand Sheard (1995) now interprets the various C-14 ages as indicating a period of activity commencing 5-4.3 ka B.P. and extending over perhaps 300 years. Nearby Mount Schank has been dated by thermoluminescence at 4.9 ± 0.5 ka (Smith & Prescott 1987) in agreement with a palaeomagnetic measurement of Barbetti and Sheard (1981) who placed the eruptions of Mount Schank and Mount Gambier either between 1 and 5 ka or older than 7 ka.

In 1987, in collaboration with CSIRO, we embarked

on a programme to date the eruptions at Mount Gambier using thermoluminescence. This technique depends on the measurement of the energy imparted to a mineral crystal over time by the ionizing radiation generated by radioactive elements in the environment and by cosmic rays; this energy is released as light when the mineral is heated in the laboratory. Its success as a dating method depends on the fact that the TL was set to zero by the event being dated, in this case either by the heat generated by the volcanic eruption or by the bleaching by sunlight of ejected material.

In the first instance samples were obtained from sites where it was considered likely that sufficient heating had taken place to reset the TL clock, and where there were likely to be sufficient quantities of quartz for an analysis. The quartz is derived from country rock sediments through which the volcanic conduit passed. The sites chosen were at Valley Lake, at Brownes Lake and at the Blue Lake crater, where there were layers of heated material underlying the lava flow. Later the scope was extended to include material which may have been blown into the air during the event, heated and/or bleached during transport and deposited in positions more or less remote from the central crater. Tuff samples were collected from several sites in the Mount Gambier and Mount Schank areas where it was thought that they might have been associated with the formation of either of the volcanoes.

Details of Samples

Details of the samples collected from the Mount Gambier complex are given in Table 1. The mineral quoted refers to the material that was extracted for the TL measurements. The quartz samples were collected and prepared according to standard practice (Huntley

* Department of Physics and Mathematical Physics, University of Adelaide S. Aust. 5005.

† Deceased

TABLE 1. Details of the samples collected in the Mount Gambier area.

Sample	Site	Lithology sampled	TL Mineral	Date Y/N
MG1b/3	Brownes Lake	Spatter lava	Quartz	N
MG2t/1	Blue Lake pump house	Heated tuff deposits	Quartz	Y
MG2S/1	Blue Lake pump house	Bridgewater Fm. sand below tuff and lava	Quartz	Y
MG2b/10	Blue Lake pump house	Hard tuff 10 cm below lava	Quartz	Y
			Fine grains	N
MG2c/12	Blue Lake cliff behind pump house	Upper tuff (c. 20 m above level of MG2S/1)	Quartz	Y
			Fine grains	N
MG2d/12	Blue Lake carpark	Banded upper tuff (same level as MG2c/12)	Quartz	Y
			Fine grains	N
MG4	Devil's Punchbowl	Sediment/tuff	Quartz	N
MG5S/0.1	Valley Lake, Nurses Landing	Baked tuff below basalt (0.1 m)	Quartz	Y
MG5S/0.3	Valley Lake, Nurses Landing	Baked tuff below basalt (0.3 m)	Quartz	Y
			Glass	N
MG5S/1.5	Valley Lake, Nurses Landing	Baked tuff below basalt (1.5 m)	Quartz	Y
MG5 lava	Valley Lake, Nurses Landing	Basalt	Quartz	N
MG6S/60	2 km south of Mount Gambier	Tuff, sunlight bleached	Quartz	Y
MG7	Potters Point Lookout	Ropy lava from path below tank	Quartz	N
SC10S/0.6	Mount Schank	Hard tuff layer	Quartz	Y
SC12S/a	Mount Schank	Hard layer of bedded tuff	Quartz	Y

et al., 1993), leading to extraction of 90–125 μm quartz grains, the yield amounting to 1 to 2% of the bulk dry weight. Fine grains containing a mixture of minerals were extracted from the 4–11 μm fraction.

The location of the sites is shown in Fig. 1.

The spatter lava at MG1b/3 is described by Sheard (1978) as representing the last evidence of volcanic activity. Unfortunately no material suitable for TL dating was extracted from it. The same outcome resulted from attempts to extract quartz from the ropery lava at MG7.

The MG2 site at the Blue Lake was extensively sampled from the sides of the crater just below the pump house where there are heated tuff layers covering sands of the Bridgewater Formation and from the cliff face above and behind the pump house where the tuff layers were deposited as a result of fall out from the eruptions.

The group of samples (MG4) collected near the Devil's Punchbowl contained terrestrial sediments of the Wangerrip Group from below the Gambier Limestone, dispersed in the volcanic tuff where it had been carried by the eruption. They were found not to have been sufficiently heated to make TL measurements.

The MG5S samples from Valley Lake were collected from the baked tuff at 0.1, 0.3 and 1.5 m below the base of the lava flow. It was not expected that the lowest level would have been sufficiently heated but it was included to check this point. A small quantity of volcanic glass was extracted from the MG5S/0.3 sample but this was highly magnetic and produced an insignificant TL signal. Basalt was also collected from this site. It contained very small quantities of extracted

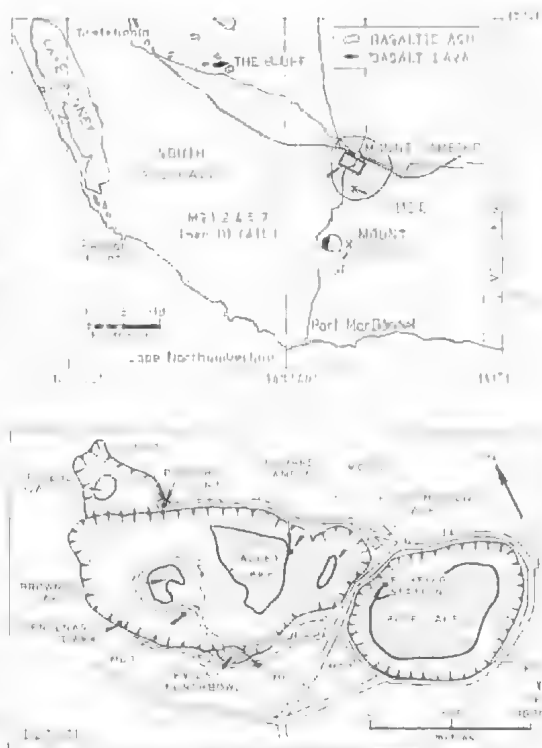


Fig. 1. Lower South-east of South Australia showing the locations of the volcanic deposits and details of the sampling sites. Adapted from Sheard (1978, 1983).

quartz, and 300 μm sections cut from the bulk sample, which might contain other minerals, yielded only low levels of TL.

Other samples of tuff and sand were collected from a site some distance to the south of the lake (MG6S/60) and from sites in the Mount Schank area (SC series), 1 km east of Mount Schank.

TL Analysis

The measurements required in order to calculate an age are the intensity of the TL in the natural sample and the TL sensitivity, as shown by the TL generated by a known amount of radiation. These two values are combined to determine the amount of radiation dose received by the natural sample, the equivalent dose. It is also necessary to measure the environmental dose rate received by the sample in the local environment. The age is then given by

$$\text{Age (ka)} = \frac{\text{Equivalent dose (Gy)}}{\text{Dose rate (Gy ka}^{-1}\text{)}}$$

where the unit of radiation dose is the gray (Gy).

The TL analysis protocol was selected according to whether the samples were thought to have been zeroed by heat (samples in the MG2 and MG5 series) or by sunlight (samples from MG6 and the SC series). In the case of the heated samples the usual procedure for pottery dating was followed (Aitken 1985). In the case of the sunlight bleached samples the selective bleach method was used (Prescott & Mojarrabi 1993); the analysis to give the equivalent dose followed the "Australian slide" method (Prescott *et al.* 1993).

Dose Rate

The sample dose rates were determined by thick source alpha counting (TSAC), by neutron activation analysis (NAA), by X-ray fluorescence spectrometry (XRS) and/or by gamma-ray scintillometry (scint), as appropriate for the estimation of the elements uranium, thorium and potassium (Prescott & Hutton 1995). The concentrations of these elements are given in Table 2 together with the calculated dose rates. The samples are grouped according to type and location and it is noticeable that the baked tuff below the layer of lava has higher concentrations of all the elements than the tuff found in other locations and also the sand from the Bridgewater Formation. Consequently the dose rates in the baked tuff are about twice those in other tuff samples and higher levels of TL might be expected in these.

For each sample the quoted concentrations of U and Th agree reasonably well (within 2 sigma limits for most of the samples) among the various methods of

analysis used, implying that the members of the U and Th decay chains are in equilibrium in these samples. The worst case is MG2S/1 which shows evidence of higher values for ^{238}U obtained by TSAC and scintillometry compared with the values obtained by DNA and by XRS. This situation has been shown to arise in cases of disequilibrium between the parent ^{238}U and its immediate decay products down to ^{234}U and the remainder of the decay chain from ^{230}Th to ^{210}Po occurring in samples collected in a similar environment at Mount Schank (Smith & Prescott 1987). The dose rates have been calculated to allow for the deficit in the early part of the chain, taking the extreme possibility of a value of $0.80 \mu\text{g g}^{-1}$ for ^{238}U - ^{234}U and $1.49 \mu\text{g g}^{-1}$ for ^{230}Th onwards.

The dose rates were derived from the element concentrations using the conversion factors of Nambi and Aitken (1986). The values quoted in Table 2 include a cosmic ray contribution of 0.10 to 0.12 Gy ka^{-1} depending on the site (Prescott & Hutton 1994). The weighted means of the various estimates of dose rate were used in the calculation of the ages of the samples.

Age Determinations

As is usual for heat-zeroed samples, first- and second-glow growth curves were obtained and the two intercepts on the dose axis combined to obtain the equivalent dose (Aitken 1985). The growth curves were fitted to a linear relationship and used to generate the equivalent dose plateau which is shown superimposed on the natural glow curve of MG2S/1 in Fig. 2. Valid

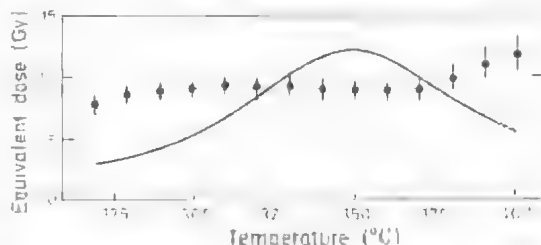


Fig. 2. Equivalent dose plateau for the MG2S/1 sample with its TL glow curve superimposed.

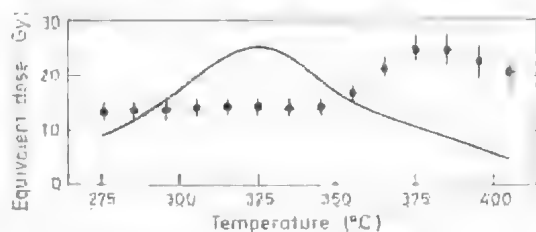


Fig. 3. Equivalent dose plateau for the MG5S/0.3 sample with its TL glow curve superimposed. The double plateau indicates two periods of heating.

TABLE 2. Concentrations of uranium, thorium and potassium in the samples, determined by thick-source alpha counting (TSAC), X-ray fluorescence spectrometry (XRS), neutron activation analysis (NAA), delayed neutron analysis (DNA) and in situ gamma-ray scintillometry (Scint.), together with the resulting dose rates.

Sample	Method	Uranium μg g ⁻¹	Thorium μg g ⁻¹	Potassium %	Dose Rate Gy ka ⁻¹
Baked tuff below lava					
MG2t/1	TSAC	2.34 ± 0.48	6.43 ± 1.61	1.25 ± 0.01	2.45 ± 0.14
	XRS	2.60 ± 0.40	8.50 ± 0.50		2.67 ± 0.10
MG5S/0.1	TSAC	2.71 ± 0.27	8.04 ± 0.92	1.82 ± 0.01	3.08 ± 0.1
	XRS	3.00 ± 0.40	10.20 ± 0.50		3.32 ± 0.1
MG5S/0.3	TSAC	2.46 ± 0.41	10.79 ± 1.38	2.19 ± 0.01	3.52 ± 0.12
	DNA, NAA	2.20 ± 0.11	9.00 ± 0.45		3.38 ± 0.06
	XRS	2.30 ± 0.40	10.40 ± 0.50		3.51 ± 0.08
	Scint.	2.62 ± 0.35	8.52 ± 0.05		3.47 ± 0.09
MG5S/1.5	TSAC	2.0 ± 0.3	6.9 ± 1.4	2.03 ± 0.05	2.61 ± 0.1
	DNA	1.87 ± 0.08			
	XRS				
MG5/Lava	TSAC	1.93 ± 0.35	4.59 ± 1.15	1.59 ± 0.01	2.52 ± 0.08
	DNA, NAA	1.10 ± 0.40	5.70 ± 0.50		2.40 ± 0.08
	XRS				
MG2b/10	TSAC	2.58 ± 0.38	8.49 ± 1.05	1.50 ± 0.01	
	DNA	2.43 ± 0.09			
	XRS				
Bridgewater Formation sand					
MG2S/1	TSAC (a)	1.44 ± 0.21	4.59 ± 0.69	0.60 ± 0.01	1.58 ± 0.07
	(b)	1.07 ± 0.20	6.66 ± 0.65		1.64 ± 0.07
	DNA, NAA	0.80 ± 0.10	5.50 ± 0.40		1.56 ± 0.05
	XRS	0.90 ± 0.40	7.40 ± 0.50		1.48 ± 0.08
	Scint	1.49 ± 0.18	5.77 ± 0.24		1.73 ± 0.05
Tuff various locations					
MG2c/12	TSAC	1.41 ± 0.26	3.03 ± 0.68	0.66 ± 0.01	1.27 ± 0.08
	XRS				
	Scint.	1.50 ± 0.12	4.32 ± 0.20		1.51 ± 0.05
MG2d/12	TSAC	1.05 ± 0.40	6.32 ± 1.36	0.71 ± 0.02	
	XRS				
MG6S/60	TSAC	1.90 ± 0.46	4.70 ± 1.70	0.74 ± 0.02	1.50 ± 0.14
	DNA, NAA	1.84 ± 0.19	6.24 ± 0.19		1.66 ± 0.13
	XRS				1.76 ± 0.07
SC10S/0.6	TSAC	2.04 ± 0.33	5.11 ± 1.15	0.74 ± 0.05	1.93 ± 0.14
	DNA, NAA	2.32 ± 0.60	7.33 ± 0.17		2.15 ± 0.15
	XRS	1.70 ± 0.17	7.70 ± 0.77		2.03 ± 0.12
SC12S/a	TSAC	1.80 ± 0.39	4.06 ± 1.33	0.94 ± 0.10	1.71 ± 0.12
	DNA, NAA	0.89 ± 0.42	5.26 ± 0.15		1.58 ± 0.10
	XRS	1.60 ± 0.16	6.70 ± 0.67		1.86 ± 0.09

dating requires that there should be a distinct plateau over a range of temperature from about 300°C to 400°C (Wintle & Huntley 1982). This condition is well met in the case of sample MG2S/1. Sample MG5S/0.3 on the other hand, has two plateaux (Fig. 3). The double plateau suggests that this sample experienced two heating events, the second one of which did not reach a sufficiently high temperature to zero the TL above 350°C. It therefore yields two ages, for differing events. Analysis of the phenomenon of the double plateau is given in more detail in Robertson *et al.* (1996). The calculated ages are given in Table 3 together with the equivalent doses and the dose rates. The analysis of MG2b/10 was not completed because there was not enough pure coarse-grained quartz.

Discussion

The ages obtained show a spread of values which are not easy to interpret but it is interesting to note that in the MG samples there is evidence of events having occurred at about 4 ka and at about 7-8 ka, coincident with other methods of dating. The figures for MG5S show the single age for the 0.1 m sample and the two ages resulting from the double plateau for the 0.3 m sample. It was expected that, as the last heating raised the temperature of the 0.3 m level to no more than 350°C, the age of the 1.5 m level would be at least 7 ka, but the very much older age (98 ± 15 ka) does not fit in with the observations and the geological interpretations (Sheard 1978, 1995). It suggests that at least

TABLE 3. Age estimates of the samples obtained from the equivalent doses and dose rates shown.

Sample	AdTL Code	Analysis	Equivalent Dose (Gy)	Dose Rate (Gy ka ⁻¹)	Age (ka)
MG2t/1	95042	Heated	9.46 ± 0.47	2.60 ± 0.03	3.64 ± 0.25
MG2S/1	95043	Heated	9.13 ± 0.32	1.45 ± 0.03	6.29 ± 0.25
MG2c/12	95044	Heated	345 ± 35	1.39 ± 0.04	250 ± 30
MG2d/12	95045	Heated	82 ± 10	1.50 ± 0.14	55 ± 12
MG5S/0.1	95039	Heated	15.7 ± 1.3	3.20 ± 0.17	4.91 ± 0.48
MG5S/0.3	95040a	Heated	14.1 ± 1.3	3.46 ± 0.05	4.08 ± 0.38
	95040b	Heated	23.9 ± 2.5	3.46 ± 0.05	7.18 ± 0.75
MG5S/1.5	95041	Heated	240 ± 40	2.46 ± 0.06	98 ± 15
MG6S/60	95046	Selective bleach	14.16 ± 0.60	1.74 ± 0.06	8.14 ± 0.44
SCI0S/0.6	95047	Selective bleach	3.21 ± 0.20	2.03 ± 0.08	1.58 ± 0.12
SCI2S/a	95048	Selective bleach	2.23 ± 0.84	1.76 ± 0.06	1.27 ± 0.48

the quartz present in this sample was actually in place well before the eruptions occurred.

The 7 ka age found here is to be compared with that reported by Leaney *et al.* (1995) for a major change in the sedimentology of the floor of the Blue Lake. However it is difficult to reconcile the time scale of the history of the Blue Lake as set by Leaney *et al.* with the violent eruptive events traced by Sheard (1978, 1990). One possibility is that Leaney *et al.* have not sufficiently allowed for the incorporation of old carbon into their inorganic samples.

The very large ages for the tuff MG2c/12 and MG2d/12, collected from the cliff face at the Blue Lake pump house suggest that this material did not in fact become sufficiently heated during the eruptions. The very recent ages for the Mount Schank samples suggest that there was some bleaching mechanism occurring 1-2 ka ago, another date which has previously been associated with events at Mount Gambier, although it is now thought that the C-14 date on which this is based may be due to intrusive tree root charcoal (pers. comm. Blackburn to Sheard 1995).

Because of the problem in TL dating of determining whether the event that is being dated removed all the existing stored energy, all the dates should be carefully considered with regard to other evidence. For example, do the two apparent groups of ages obtained, i.e. c.4 ka and c.7 ka really indicate two eruptions separated by 3 ka? During this time interval there should have been considerable weathering of any tuff ejected. However, the chemistry of the tuff samples MG5S/0.1, MG5S/0.3 and MG2S/1 (grouped together in Table 2) shows that the ratio of the more soluble and mobile elements, sodium, magnesium and phosphorus to the insoluble element, titanium, is the same as that found for the solid lava. Thus the lava must have protected the tuff very soon after it was deposited. There are also no known palaeosols developed within this tuff or on top of the lava (Sheard 1990). The exposed tuff MG6S/60 does show considerable weathering with the loss of about 50% of the soluble elements in relation

to titanium. Incidentally the loss of elements from MG6S/60 is about the same as the loss of the same elements from the similar site SCI0S/0.6 near Mount Schank. The age of the Mount Schank eruption was found to be 4.9 ± 0.5 ka by Smith and Prescott (1987) using well baked tuff/sand under the lava flow and the age of MG6S/60 should be similar. These chemical considerations support the suggestion that neither heating nor exposure to sunlight has been sufficient in some of the samples to remove all of the pre-existing TL.

M. J. Sheard (pers. comm.) states, "The phreatic style of eruption so evident at Mount Gambier (i.e. associated with copious H₂O) means that many eruptive products incorporating exotic quartz may not have been raised much above 100°C. . . . In addition, under high volume tephra explosions some or most of the exotic quartz could escape light bleaching (i.e. resetting) due to ash cloud or surge cloud density and subsequent rapid fallout and burial. Thus, it is possible to have exotic quartz grains, only partially reset or left with their "older" TL signature, incorporated into much younger tephra." Sheard's remarks seem to indicate the possibility of finding samples containing partially heated quartz grains mixed with thoroughly bleached tephra, and so possibly being able to detect different dates for different sized grain fractions. With this end in view, an attempt was made to date the fine grain fraction of the samples from which quartz grains had been extracted, but it was found in the three samples tested (MG2t/10, MG2c/12 and MG2d/12) that either there were insufficient fine grains or that the fine grains showed no TL and no sensitivity to radiation.

The TL dates in conjunction with other geochronological evidence have reinforced the belief that there was volcanic activity at Mount Gambier at about 4 ka ago, and that there may have been activity at 1.5 and 7 ka, but that the latter dates should be accepted with caution. The investigations have also illustrated that

it is often difficult to select appropriate samples for TL dating from a complex system like the one at Mount Gambier.

Acknowledgments

The late John Hutton was associated with all of the work described here. It is a matter of regret that he

did not see the final publication. The project was begun in collaboration with CSIRO and the work was supported by CSIRO and the Research Fund of the University of Adelaide, and by AINSE. Kym Lawry, Adrian Murphy and Phillip Stamatelopoulos assisted with the work. M. Sheard and D. Leaney gave much useful advice.

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NEMATODES ASSOCIATED WITH DIPTERA IN SOUTH AUSTRALIA: A NEW SPECIES OF FERGUSOBIA CURRIE FROM A FERGUSONINID AND A NEW RECORD OF SYRPHONEMA LAUMOND & LYON FROM A SYRPHID

By KERRIE A. DAVIES & JANINE LLOYD**

Summary

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Key Words: Taxonomy, Nematoda, *Fergusobia*, Diptera, *Syrphonema*, new species, new record.

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Introduction

This paper describes a new species of the tylenchid nematode *Fergusobia*, the only genus of nematode known to parasitize both a plant and an insect (Maggenti 1981). It has a bipartite life cycle, with a generation parasitic in galls on Myrtaceae followed by one parasitizing the fergusoninid fly *Fergusonina* Malloch. Also reported is the first collection outside France of the rhabditid nematode genus, *Syrphonema*. Both nematodes were collected in Adelaide, South Australia.

Materials and Methods

Nematodes were collected from galls cut open in tap water, relaxed and fixed in hot FA 4:1. Insects were dissected in 0.85% saline, and nematodes from these were fixed as above. Nematodes were transferred from fixative to 1% glycerol in 30% ethanol in glass blocks and placed in a desiccator containing 96% ethanol for 2 days. For the following 14 days nematodes were kept at 40°C and the blocks were partially covered with glass lids. During the first three days, one or two drops of a solution of 5% glycerol in 95 ml ethanol were added four times daily. Slow evaporation was continued thereafter. For light microscopy, processed nematodes were mounted in glycerol on glass slides and examined using interference microscopy. Scanning electron microscopy studies were made. Nematodes were taken from glycerol, passed through a series of ethanol/glycerol solutions with increasing proportions

of ethanol and washed three times with 100% ethanol. They were then dried using CO₂ in a critical point drier, mounted on stubs, sputter coated with approximately 30 nm of gold and viewed at 20 kV.

Measurements are in μ m. Drawings and measurements were made from material mounted in glycerol using a camera lucida. Body width was measured at mid-length. Spicules were measured along the mid-line in lateral view. De Man's ratios, i.e. V = anterior end to vulva as percentage of body length, T = length of testis from cloaca to flexure as percentage of body length, a = length divided by greatest body width, b' = length divided by distance from anterior end to base of oesophageal glands, c = length divided by tail length, c' = tail length divided by width at anus were determined. Comparisons were made with described species using published descriptions, specimens of parthenogenetic females of *Fergusobia magna* Siddiqi (Queensland Museum (QM) G200512-200519) and specimens of all stages except parasitic females of *F. tumifaciens* Currie isolated by the authors from flower bud galls on *Eucalyptus camaldulensis* Dehn, at Urrbrae, South Australia (Waite Institute Nematode Collection (WINC) 943). The holotype of the new species is deposited in the South Australian Museum, Adelaide (SAM).

Taxonomic descriptions

Fergusobia fisheri sp. nov.
(FIGS 1-2)

Holotype: Parthenogenetic ♀, Black Forest, South Australia (34°57'S, 138°34'E), 3.viii.1993, W. Frost, collected from a leaf gall on a hybrid of *Eucalyptus leucocylon* F. Muell., AHC207051 (SAM).

* Department of Crop Protection University of Adelaide, PMH 1 Glen Osmond S. Aust. 5064

part with valve-like structure, followed by short narrow "isthmus" which widens abruptly to broader part associated with the oesophageal glands; oesophago-intestinal junction obscure. Lumen of tract broadens posterior to "valve" and again at level of secretory-excretory pore. Oesophageal glands large, occupying about three quarters of body width, extending over intestine to about 55% of total body length; dorsal gland with large nucleus. Secretory-excretory pore 50-92 μm from anterior end with short duct leading directly to excretory cell. Nerve ring at base of swollen anterior part of digestive tract. Hemizonid not seen. Reproductive tract with single gonad, prodelphic, extending to nerve ring; oviduct flexed in some females; uterus with quadricolumnellar, often contains single egg, curves to join vagina, which is directed slightly forwards. Vulva usually conspicuous depressed transverse slit, but in some specimens, vulval lips protrude slightly. Cuticle wrinkled on ventral side just anterior to vulva in half specimens examined. Rectum simple tube, without obvious musculature; anus inconspicuous pore, usually associated with distinct indentation in the cuticle. Tail conoid, narrowing sharply to rounded tip, 1.0-1.4 times as long as anal body width. Phasmids not seen.

Occurs in leaf gall. Dorsally curved when relaxed by heat, with ventral side convex, to form open C-shape. Smaller than amphimictic preparasitic female. Cuticle weakly annulated, striated; lateral fields obscure. Cephalic region small relative to width of body at anterior end, off-set, lightly sclerotized; region appears roughly circular, unstriated, with 8 sectors; dorsal and ventral sectors less than half width of each of others; in side view sectors with rounded outline and no central elevation around stylet opening. Amphidial openings pore-like, situated near dorsal edge of lateral sector. Stylet slender; conus forming half length; small fusiform basal knobs. Orifice of dorsal oesophageal gland approximately $3\text{ }\mu\text{m}$ posterior to stylet knobs. Digestive tract with swollen anterior

[illegible]

Description of infective pre-parasitic female (Fig. 1B, F, G)

Occurs in leaf gall, infects mature larval stage of fly. Anterior part of nematode straight when relaxed by heat; posterior part curved dorsally. Maximum body width at mid-length. Cuticle with inconspicuous annulations; strongly striated; lateral fields arising about one body width behind head, with irregular, broken striae, obscure when viewed with light microscope. Cephalic region continuous with body, weakly sclero-

tized. Stylet slender, weakly sclerotized with smaller basal knobs than in parthenogenetic female. Amphids not seen. Orifice of dorsal oesophageal gland approximately $3\text{ }\mu\text{m}$ posterior to stylet knobs. Secretory-excretory pore approximately half the distance along the oesophageal glands ($65\text{--}90\text{ }\mu\text{m}$ from anterior end). Nerve ring at base of swollen anterior part of digestive tract. Hemizonid not seen. Oesophageal glands often obscure, elongate, occupying about half body width, extend over intestine to about 30% total body length. Anterior part of digestive tract swollen,

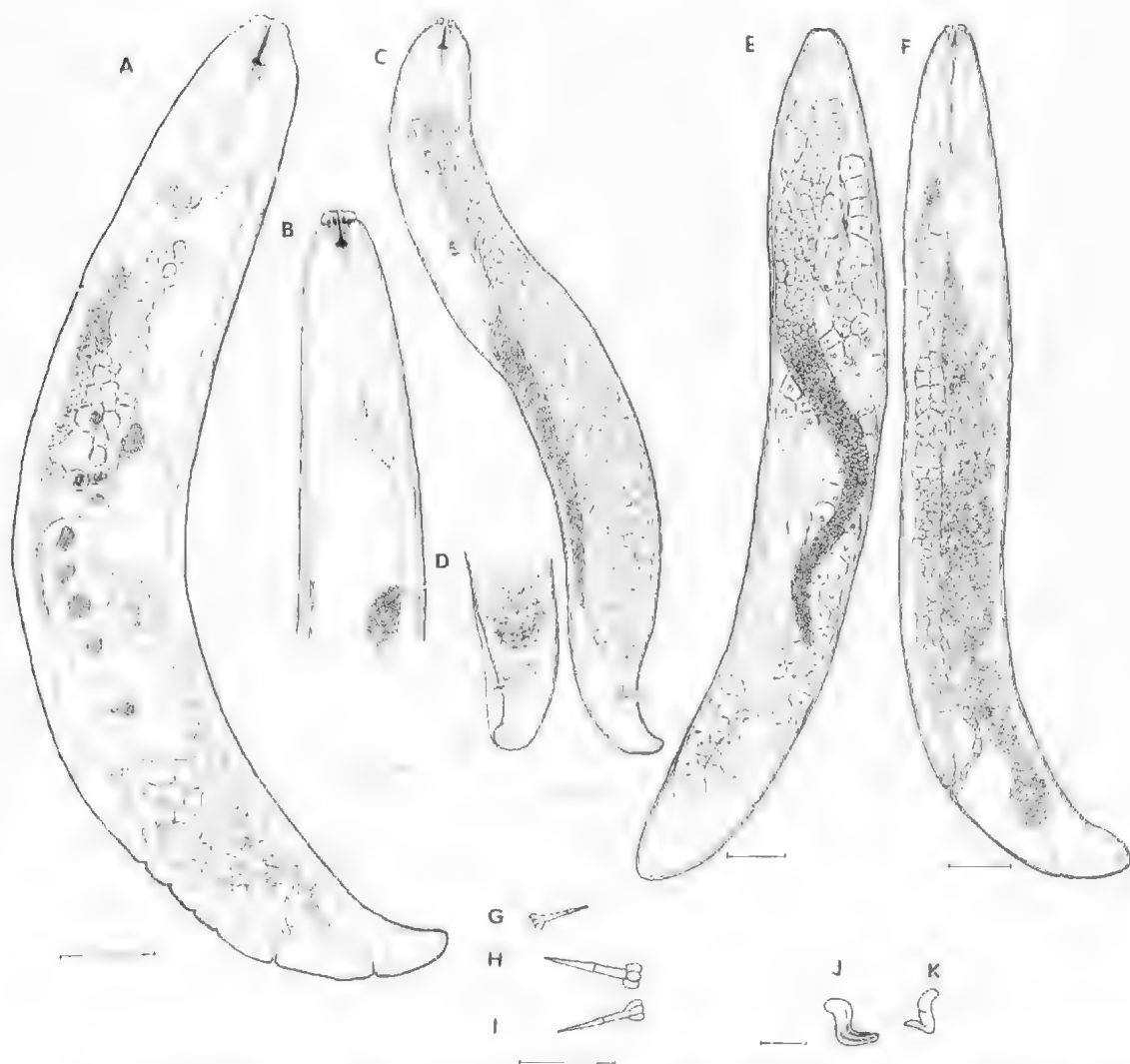
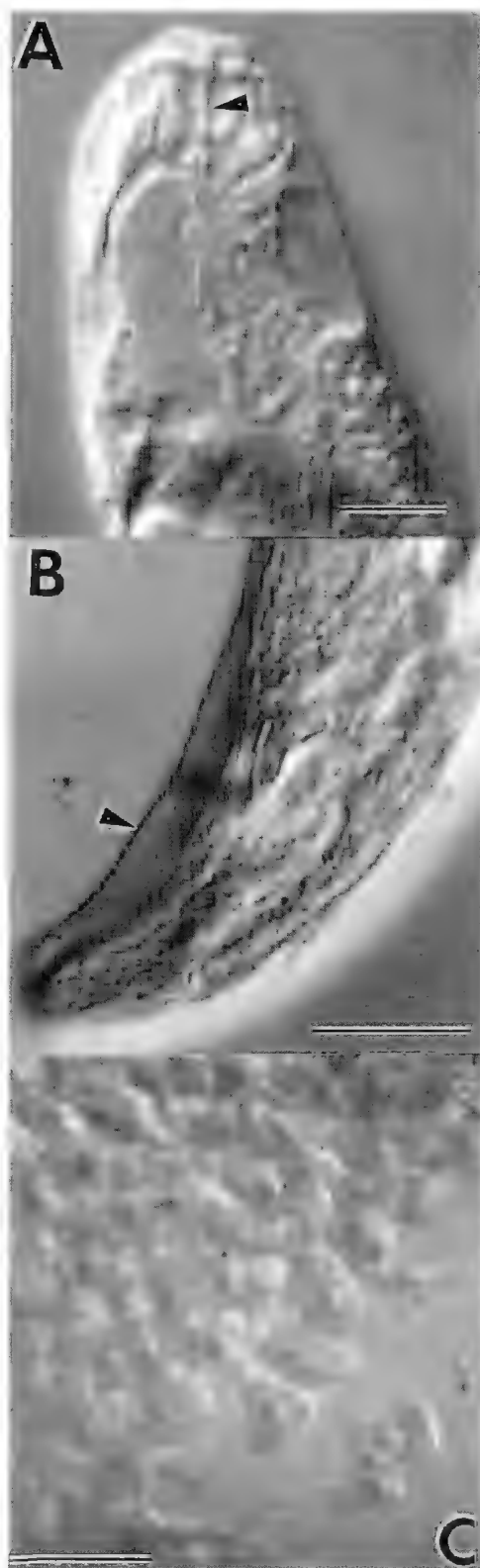


Fig. 1. *Fergusobia fisheri* sp. nov. A. Entire parthenogenetic female. B. Head of pre-parasitic female. C. Entire male (bursa not seen due to angle at which tail viewed). D. Detail of male tail, ventro-lateral view, showing bursa and angulated spicule. E. Entire parasitic female. F. Entire pre-parasitic female. G, H, I. Stylets of pre-parasitic female, parthenogenetic female and male, respectively. J, K. Lateral and dorsal view, respectively, of spicule. Scale bars = $10\text{ }\mu\text{m}$ G H I J K, $20\text{ }\mu\text{m}$ A B C D F, $80\text{ }\mu\text{m}$ E.



non-muscular with valve-like structure. Intestine may contain many dense granules or lumen may be broad and empty, possibly reflecting nutritional status. Cells of intestinal walls have prominent nuclei with large nucleoli. Uterus extends almost to base of oesophageal glands, acting as spermatheca and packed with sperm; no post-vulval sac; vagina directed anteriorly, plugged with refractile material; oviduct short, often with flexure; ovary extending to nerve ring. Vulva transverse slit, inconspicuous; lips may be raised. Anus pore-like; rectum very small, non-muscular. Tail almost hemispherical. Numerous large nuclei scattered along length of nematode in epidermis.

Description of parasitic female (Fig. 1E)

Occurs in haemocoel in abdomen of fly. Epidermis thickened. Cephalic region may or may not be offset. Body swollen, sausage-shaped, obese, filled with hypertrophied reproductive organs. No stylet seen. Oesophagus and intestine degenerate, anus not seen. Ovary convoluted. Several eggs in uterus at one time. Vulva depressed transverse slit.

Description of male (Figs 1C, D, I, J, K; 2B, C)

Occurs in leaf gall. Body shape variable when relaxed by heat, posterior portion of body may be arched dorsally, tail curved ventrally. Cuticle with longitudinal striations, without annulations; lateral fields indistinct under light microscope, appear to be 3 or 4 incisures or several irregular striae. Cephalic region off-set, with lightly sclerotized framework. Stylet, oesophagus, intestine and secretory-excretory pore all as for parthenogenetic female. Oesophageal glands extend over intestine to about 35% of total body length. Reproductive tract with single testis, extending to nerve ring; extensive vas deferens, with amoeboid sperm. Bursa membranous, smooth, often difficult to see; extends to tail tip, appears to be peloderan; collapsed in specimens prepared for SEM, seen as wrinkled membrane lying on cuticle of tail region; variable length, usually arises 1.5-2 tail lengths anterior to cloaca, but in one specimen arose in anterior half of nematode. No genital papillae seen. Spicules robust, paired, angular near their middle so that manubrium and shaft appear to be perpendicular to each other in ventral view; manubrium large. No gubernaculum. Tail bluntly rounded.

Fig. 2. *Fergusobia fisheri* sp. nov. A. Parthenogenetic female head to show buccal region and stylet (arrow). B. Male tail showing bursa (arrow). C. Amoeboid spermatozoa from squashed male. Scale bars = 10 μ m.

Diagnosis and relationships

F. fisheri sp. nov. is characterized by having a parthenogenetic female with the cephalic region small relative to the body width, with a flat terminal profile, the vulval slit in a conspicuous depression of the cuticle, the anal opening in a similar but smaller depression and a short tail (0.9–1.3 times anal body width) with a narrow cone shape. The male has angular spicules with a large manubrium.

F. fisheri sp. nov. differs from *F. jambophila* Siddiqi in having a flat cephalic region without a central conical elevation and angular spicules and from *F. indica* (Jaisrjuri) and *F. magna* because the parthenogenetic female has a short tail. The anus opens into an obvious cuticular depression in the parthenogenetic female of *F. fisheri* sp. nov. but not in the other described species. *F. fisheri* sp. nov. assumes a similar shape to *F. tumifaciens* when heat-killed but is smaller (average length of parthenogenetic females 253 and 318 µm respectively and of males 336 and 420 µm. Measurements for *F. curriei* (= *tumifaciens*) from Fisher and Nickle (1968). The parthenogenetic female of *F. fisheri* sp. nov. has a smaller cephalic region relative to body width than *F. tumifaciens* and may have wrinkled cuticle on the ventral side of the body anterior to the vulva, absent in *F. tumifaciens*. The vulval slit is situated in a distinct cuticular depression in *F. fisheri* sp. nov. as in *F. jambophila* and *F. indica*, but not in *F. tumifaciens* or in *F. magna*. The volume of the tail of the parthenogenetic female is smaller in *F. fisheri* sp. nov. than in *F. tumifaciens*, having a narrower cone shape. The point of origin of the caudal alae is variable in *F. fisheri* sp. nov. males, in contrast to *F. tumifaciens*.

Etymology

Named after Dr J. M. Fisher, formerly of the Department of Crop Protection University of Adelaide.

Biology, life cycle and general comments

The nematode *F. fisheri* sp. nov. was found on leaf galls of the southern blue gum, *E. leucotylan*, in association with an unknown species of the fergusoniid fly *Fergusonina* sp. Galls were first collected in early August 1993, followed by successive collections until October 1993 when no nematodes or flies were found. In the early August collection, galls contained many nematodes (juveniles, parthenogenetic and infective females and males) and fly larvae. Of 32 larvae dissected, the abdomen of two contained a total of three fertilized infective females and one male nematode. A week later, 14 fly larvae and 15 puparia were collected from galls and dissected. Six of the larvae contained two to four fertilized infective female nematodes. No nematodes were found in puparia. In early September, galls contained a few adult male and infective female nematodes. Puparia contained pharate

adult flies. Nineteen pharate adult flies were dissected, eight of which were male and had no nematodes. However, 10 of the 11 female flies contained from 1–11 (average 6.4) mature parasitic female nematodes per fly. In six of these, eggs had been laid in the haemolymph and in most cases, the eggs were in the early stages of embryonic development. One fly, however, contained eggs in which the juvenile nematodes were well-formed.

These observations on the life cycle generally agree with those reported by Fisher & Nickle (1968) for *F. curriei* (= *tumifaciens*). No nematodes have been found in male flies. Eggs are laid in the haemolymph of the abdomen of the fly but it is not known how the fly deposits both insect eggs and nematode juveniles into *Eucalyptus* tissue. Presumably, these nematode juveniles develop into parthenogenetic females which lay eggs. It is possible that juveniles developing from the early eggs become males, as in *F. tumifaciens*. While the first collection of *F. fisheri* sp. nov. from leaf galls yielded all plant parasitic stages of the nematode, the fourth stage juveniles found were all female (distinguished from males by a more bluntly rounded tail and development of the uterus), suggesting that male development had occurred earlier. Fisher & Nickle (1968) stated that only fertilized infective-stage females of *F. curriei* (= *tumifaciens*) penetrated fly larvae but female and male *F. fisheri* sp. nov. have been found in fly larvae. *F. tumifaciens* may deposit eggs in the haemolymph of the fly before it emerges as an adult female (Currie 1937) or this may be delayed until after emergence of the fly from the gall (Fisher & Nickle 1968). Here, *F. fisheri* sp. nov. had produced eggs before the parasitised fly had emerged from the puparium.

Currie (1937) described one species, *F. tumifaciens*, associated with *Fr. carteri* Tonn. from leaf galls on *E. Stuartiana* (sic) E. v. M. He also observed minor morphological differences between nematodes collected from leaf bud, axil bud, stem tip and flower bud galls associated with a number of other fly species on more than a dozen species of eucalypt. He suggested "further work will show that the nematodes associated with the different flies have differences in structure which entitle them to be considered as different species" (Currie 1937). These differences included variation in the point of origin of the caudal alae and the size and position of the oesophageal glands. Observations of material held in the WINC confirm that these characters will be important in species differentiation. Fisher & Nickle (1968) redescribed *F. curriei* (= *tumifaciens*) from flower bud galls on *E. camaldulensis* Dehnh. associated with *Fr. allyardi* Tonn. Of the other described species of *Fergusonina*, Siddiqi (1986) described *F. magna* from *Eucalyptus* stem galls associated with an unknown fly host and from soil under host trees, *F. indica* from soil in India

and *F. jambophila* from flower bud galls on *Syzygium cumini* (L.) Skeels associated with *Fn. syzygii* Harris.

The Waite Institute Nematode Collection contains specimens of *Fergusobia* collected from stem, bud and leaf galls on *Eucalyptus* from Adelaide and Mt Gambier, respectively, which appear to be undescribed species. Fisher (pers. comm.) found an undescribed species of *Fergusobia* in leaf galls on *E. camaldulensis* associated with *Fn. lockharti* Torr. It is apparent, given the different forms of galls, that each of these undescribed species of nematode is associated with a different species of *Fergusonina*. Each, however, is not necessarily restricted to one species of *Eucalyptus*. Presumably the nematode has evolved mechanisms, which are probably host-specific, to escape the fly's immunological system during the generation in which it is an insect parasite. Thus, *Fergusobia*, like the genus *Anguina* Scopoli (Krall 1991) may have a high degree of host specificity; in this case, for the insect host. If so, Currie (1937) and Fisher & Nickle (1968) may not have described the same species of nematode, given that they were associated with different species of *Fergusonina*. Indeed, Currie refers to the margins of the caudal alae of males of his specimens of *F. tumifaciens* as being slightly crenate, a character not observed by Fisher & Nickle (1968) nor in specimens isolated from *E. camaldulensis* by the present authors. Also, the oesophageal glands of the parthenogenetic female of the specimens from *E. camaldulensis* are longer than in Currie's description and drawing of *F. tumifaciens*.

The structure of the digestive tract of *Fergusobia* remains unclear. Given the small size of these nematodes, and their typical dark colouration, it is very difficult to distinguish the anterior parts of the tract. Fisher & Nickle (1968) described the anterior part of the oesophagus as swollen, narrowing abruptly to form a short isthmus at the level of the nerve ring, then broadening again to contain the large glands. They believed that the oesophago-intestinal junction occurred at about the level of the secretory-excretory pore. Siddiqui (1986) interpreted the anterior swelling of the digestive tract as a "pseudo-pharynx" and believed that the valve-like structure it contains marked the

junction of the oesophagus and intestine. An electron microscope study of the anterior part of the digestive tract of *Fergusobia* is needed to decide which of these interpretations is correct.

Syrphonema sp.
(FIG. 3)

Measurements: Table 2.

Description of female (Fig. 3C, D, E, F, G)

Nematodes straight or slightly C-shaped when relaxed by gentle heat. Cuticle has longitudinal grooves with many fine transverse markings; often appears loose at head and/or tail; lateral lines large (31 μ m wide, 27-33 μ m), with smooth ribbon-like appearance and single central ridge. Lip region often indistinct; six separate lips, each with small papilla. Stoma cup-shaped; cheilostom reduced; promesostom about 4 μ m long, and about same width; thickening of cuticle on ventral side of metastom, which makes stoma asymmetrical, and may form a rhabdion; telostom present. Amphid openings at base of lateral lips. Oesophagus rectilinear; no true bulb; vestigial valve present. Nerve ring situated in posterior third of oesophagus. Secretory-excretory pore opening just behind nerve ring; prominent excretory cell just behind oesophago-intestinal junction. Deirids not seen. Hemizonid just posterior to nerve ring. Intestinal lumen lined with refractive material from oesophago-intestinal junction to rectal valve; lumen wide in young females but narrower in older. Three rectal glands. Reproductive tract with single gonad, amphidelphic, with genital tube running anteriorly; ovoviviparous; long uterus, extending almost to point of flexure of genital tube just behind oesophago-intestinal junction; oviduct extending back down dorsal side of body; small post-uterine sac present; no true spermatheca, sperm not seen; vulva with transverse opening, well-developed associated musculature; posterior vulval lip often more prominent than anterior; vagina not directed anteriorly or posteriorly. Phasmids not seen. Tail conical, terminus variable (Fig. 3).

TABLE 2. Measurements for adult females of *Syrphonema* sp. isolated from Adelaide. All measurements in μ m

	Length	Width	Anterior end to base of bulb	Tail length	Anterior end to vulva	V	a	b	c
mean	147.0	49.7	140.5	106.0	120.0	81.6	29.3	10.6	13.8
n	12	12	10	10	12	12	12	10	10
S.D.	23.6	6.8	20.5	16.9	22.0	5.7	3.6	1.7	1.5
range	123.0-189.0	32-56	118-171	83-130	91.0-162.0	66.9-86.5	25-36	8.2-13.4	11.4-16.0

Description of juveniles (Fig. 3A, B)

Second stage juveniles 573 μm (473-624; $n=8$); third stage juveniles 830 μm (806-873; $n=3$); fourth stage juveniles 1062 μm (920-1260; $n=7$).

As for adult females, except that the lateral lines consist of a single central ridge only. Gonad primordium well-developed in third and fourth stage juveniles, developing uterus particularly obvious in fourth stage nematodes, enabling rapid determination of the various juvenile stages.

Collector, host and locality

The nematodes were dissected from the intestine of two females of the syrphid fly *Simosyrphus grandicorinis* (Macquart), collected on sow thistle, *Sonchus* L. sp., at the Waite Campus of the University of Adelaide, Glen Osmond in January and December 1993 by Mr E. Soleyman. Nematode specimens are held in the WINC 687.

Biology and general comments

A search of Helminthological Abstracts suggests that this is only the second record of the genus *Syrphonema*, erected by Laumond & Lyon (1971), and the first outside France. Its occurrence in South Australia suggests that the genus may have a cosmopolitan distribution. Laumond & Lyon (1971) collected *S. intestinalis* from the digestive tracts of 12 species of syrphid flies. The infected flies found here were part of collections made in a study of the biology of the syrphid flies, *S. grandicorinis* and *Melangyna viridiceps* (Macquart). No nematodes were seen in dissections of 305 *M. viridiceps* and only two of 105 *S. grandicorinis* dissected contained nematodes (Soleyman pers. comm.) suggesting that the infection rate is naturally low. It is not known what effect, if any, infection has on the survival and reproductive capacity of the fly.

The nematodes described here from South Australia were classified as *Syrphonema* on the basis of the host fly, rectilinear oesophagus without a bulb and with a vestigial valve and because the female is ovoviviparous and has a posterior vulva. In the absence of males, it is not possible to decide if the nematode is *S. intestinalis* or a new species. The body lengths of the South Australian and French forms suggest that the former were smaller, but the De Man ratios are very

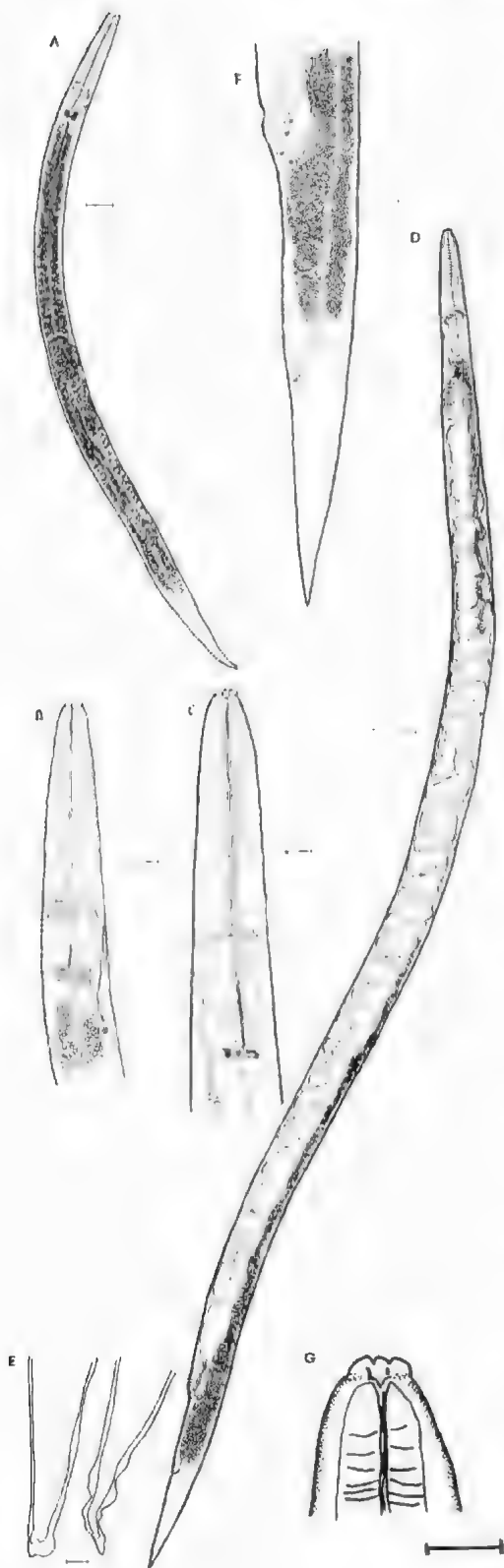


Fig. 3. *Syrphonema* sp. A. Entire fourth stage juvenile. B. Anterior of fourth stage juvenile. C. Anterior of adult female. D. Entire adult female. E. Variable tail shapes of adult females. F. Vulva and tail of female. G. Stoma of adult female. Scale bars = 10 μm B C E F G, 20 μm A, 50 μm D.

close (Table 2). Some apparent morphological differences have been observed. Laumond & Lyon described the stoma of their specimens as reduced and "vestibule-formed"; in the nematodes described here the stoma was cup-shaped but asymmetric with cuticular thickening (possibly a rhabdion) of the ventral metastom. The nerve ring seems to be located more posteriorly in the South Australian than in the French specimens. Again, the drawing of the female in Laumond & Lyon (1971) does not show a post-uterine sac or a protuberant posterior vulval lip, both present in the specimens examined here. While Laumond & Lyon state that *S. intestinalis* does not have a spermatheca, they have drawn a structure, also seen in South Australian females, which could function as a spermatheca. This is an apparent modification of the reproductive tube, just on the uterine side of the flexure

of the oviduct; however, no sperm were seen. An attempt to obtain material from France for comparative studies was unsuccessful.

Acknowledgments

We thank Dr D. N. McAlpine, Australian Museum, Sydney for identification of adult *Fergusonina* collected from Black Forest, Dr J. Gardiner, University of Adelaide, for identification of *E. leucoxyton*, Dr W. Frost for collecting leaf galls, Mr E. Soleyman for specimens of *Syrphonema* and information on infection rates and Mrs F. Reay and Mr G. Taylor for helpful criticism of the manuscript. This work was supported by a grant from the Australian Biological Resources Study.

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PRELIMINARY INVESTIGATIONS OF DUNES OF THE GAWLER RANGES PROVINCE, SOUTH AUSTRALIA

By E. M. CAMPBELL, C. R. TWIDALE*, J. T. HUTTON† & J. R. PRESCOTT‡*

Summary

Campbell, E. M., Twidale, C. R., Hutton, J. T. & Prescott, J. R. (1996) Preliminary investigations of dunes of the Gawler Ranges province, South Australia. Trans. R. Soc. S. Aust. 120(1), 21-36, 31 May, 1996.

Three fields of dunes have developed in the recent past within the Gawler Ranges in the arid-semiarid interior of South Australia. The dunes (lunettes, parabolic dunes, transverse dunes, linear dunes, climbing dunes and falling dunes) are essentially relic forms, were active about 4000 years BP and are now stabilised by vegetation though strong winds still cause occasional sand movement. Some of the dunes demonstrate sand transport over distances of at least 25 km. The origin of the various morphological dune types is discussed. Supply of sand, the moisture content of the substrate, the vegetation cover and wind speed and direction are all important. Topography influences the morphology of the dunes in various ways and is fundamental to any explanation of climbing and falling dunes.

Key Words: Gawler Ranges, lunettes, parabolic dunes, transverse dunes, linear dunes, climbing dunes, falling dunes, thermoluminescence dating.

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by E. M. CAMPBELL*, C. R. TWIDALE*, J. T. HUTTON† & J. R. PRESCOTT‡

Summary

CAMPBELL, E. M., TWIDALE, C. R., HUTTON, J. T. & PRESCOTT, J. R. (1996) Preliminary investigations of dunes of the Gawler Ranges province, South Australia. *Trans. R. Soc. S. Aust.* 120(1), 21-36, 31 May, 1996.

Three fields of dunes have developed in the recent past within the Gawler Ranges in the arid-semiarid interior of South Australia. The dunes (lunettes, parabolic dunes, transverse dunes, linear dunes, climbing dunes and falling dunes) are essentially relic forms, were active about 4000 years BP and are now stabilised by vegetation though strong winds still cause occasional sand movement. Some of the dunes demonstrate sand transport over distances of at least 25 km. The origin of the various morphological dune types is discussed. Supply of sand, the moisture content of the substrate, the vegetation cover and wind speed and direction are all important. Topography influences the morphology of the dunes in various ways and is fundamental to any explanation of climbing and falling dunes.

KEY WORDS: Gawler Ranges, lunettes, parabolic dunes, transverse dunes, linear dunes, climbing dunes, falling dunes, thermoluminescence dating.

Introduction

In the mid-latitude deserts extensive fields of sand dunes are restricted to plains. Sand dunes have, however, been reported from desert uplands where topographic obstacles deflect or funnel the regional airflow and produce depositional forms and patterns different from the essentially regular and repeated formations found in the dunefields of the adjacent plains (Wilson 1973; Smith 1982). They include sand shadows of various types, sand sheets, obstacle dunes and climbing and falling dunes (Planhol & Rognon 1970; McKee 1979; Mainguet 1984; Greeley & Iverson 1985). The Gawler Ranges, located in the arid-semiarid interior of South Australia, is a desert upland within which three fields of sand dunes have penetrated the valleys between the bornhardt massifs and in some areas have overridden the low domical hills (Fig. 1a, b).

Geologic Background

The bornhardts of the Gawler Ranges are developed in a layered sequence of silicic volcanic rocks (mainly rhyolites, rhyodacites and dacites) of Mesoproterozoic age (1592 ± 2 Ma - Fanning *et al.* 1986). The volcanic rocks consist predominantly of subaerially erupted ignimbrites (*nuées ardentes* deposits), welded to varying degrees, and with local occurrences of basaltic lava and agglomerate. They were intruded by granites of the Hiltaba Suite (1485 ± 16 Ma - Creaser 1989

cited by Blissett *et al.* 1989; see also Flint 1993) which now occur extensively in the western part of the upland, in the Kondoolka and Hiltaba areas, as well as in small isolated outcrops near Kokatha Homestead (H.S.) and Lake Everard H.S. They are also exposed to the W, SW and S of the Ranges.

Where exposed, both the volcanic and granitic crystalline rocks are massive and compact but a well developed system of orthogonal fractures trending NNW and NE, and including also latitudinal and



Fig. 1a. The Gawler Ranges province, showing location of the study site in South Australia (inset), localities mentioned in the text and average annual isohyets (mm). The Corrobinnie Depression dune samples analysed by Gostin were collected from dunes adjacent to the road from Wirulla to Hiltaba H.S.

* Department of Geology and Geophysics, University of Adelaide S. Aust. 5005.

† Deceased.

‡ Department of Physics, University of Adelaide S. Aust. 5005.

meridional sets, has been exploited by weathering and erosion to form the major valley systems of the Ranges (Campbell & Twidale 1991). The summit and upper slopes of the bornhardts are essentially devoid of any weathered materials, though isolated patches of regolith

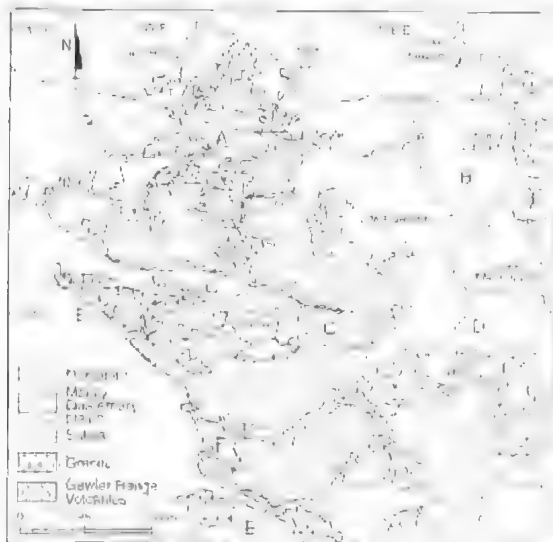


Fig. 1b. The geology, including dunefields, of the Gawler Ranges province (after Williams 1994). A. Hiern Dunefield. B. Piccadilly Dunefield. C. Moonaree Dunefield. D. Beacon Dunefield. E. Ilkina Dunefield. F. Scrubby Peak Dunefield.

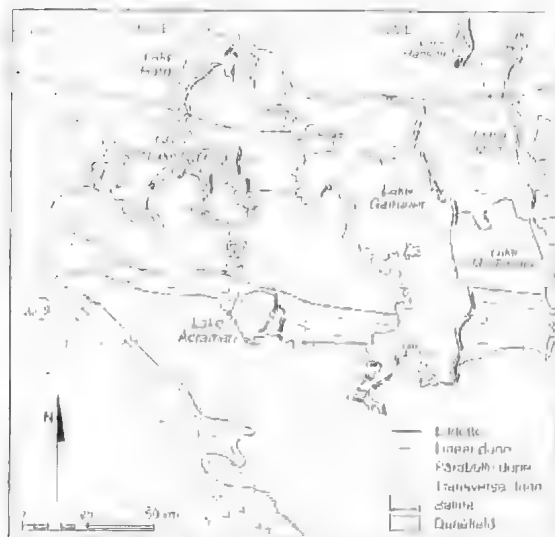


Fig. 1c. Schematic diagram showing location of lunettes, linear dunes and parabolic dunes of the Gawler Ranges province, South Australia. The orientation of the linear dunes is also indicated. Not all dunes are shown.

are preserved on the lower slopes, as for example 7 km east of Nonning H S., and in the valley floors drill cores and dam sections indicate that the volcanic material is weathered to depths of up to 50 m. Individual bornhardts attain heights of over 460 m in the S, but they decline in elevation to the N (e.g. Nukey Bluff c. 460 m, Mt Nott 430 m, Bond Hill 336 m, Chitanilga Hill 317 m, Nuckulla Hill 256 m, Mortimer Hill 232 m – see Fig. 1a). The upland is bounded on its SW and S sides by an escarpment which, though dissected and rising only 150–200 m above the surrounding plain, is nevertheless, and viewed regionally, linear and imposing, so much so that the explorer E. J. Eyre was led to describe the Gawler Ranges as “a vast mountain mass rising abruptly out of the low scrubby country” (Eyre 1845). To the N, W and E the relict amplitude diminishes and the hills peter out as the plains become more and more extensive.

The bornhardts of the Gawler Range province have evolved in two major stages. The first involved planation and fracture-controlled differential subsurface weathering in Jurassic or earlier times, the second, the stripping of the regolith in the Early Cretaceous to expose bevelled domical forms. Remnants of the etch planation surface represented by the summit bevels are particularly well preserved in the south. There has been only minor erosion of the ranges since the Mesozoic (Campbell 1990¹; Campbell & Twidale 1991).

Numerous salinas, including lakes Gairdner, Harris, Everard and Acraman and many small saline playas, occupy low lying areas in valleys and plains. The depression occupied by Lake Acraman is the site of an ancient meteorite impact (Williams 1994). The large lakes stand about 120 m above sea level. They are the termini of closed drainage basins most of which are not much larger than the lakes themselves.

Climate

At present the area is semiarid in the S grading to arid in the N (Fig. 1a). In the south there is a pronounced winter rainfall maximum, produced predominantly by the easterly passage of cold fronts, but a significant proportion of the rainfall is derived from occasional influxes of moist tropical air. In the north the rainfall is derived from both these sources and the annual distribution is more uniform (Fig. 2a; Bureau of Meteorology 1993a). Summers are hot and winters cool. Annual evaporation is about 2700 mm, with a mean monthly evaporation ranging from about 80 mm in June to 390 mm in January.

The only records for modern wind regimes in the area are from Nonning (Fig. 2b). In summer, sand-moving winds (stronger than about 20 km per hour) blow predominantly from SE, S and SW. In winter, strong winds blow from several quarters but N, NW

¹CAMPBELL, E. M. (1990) Structure and surface in the Gawler Ranges, South Australia. PhD thesis, University of Adelaide (Unpub.)

and SW winds are important (Bureau of Meteorology 1993b). Woomera, located more than 100 km to the NE of the Ranges, experiences predominantly SE-S (total) winds in summer although in winter, winds are more variable, but with a strong N and NW-SW component. At Ceduna, 100 km to the W, in summer SE, S and SW winds predominate, whilst in winter NE through NW-SW winds are most common (Bureau of Meteorology 1988; Fig. 2c).

The Dunefields

The Australian dunefields form a huge whorl of linear dunes around the centre of the continent (Brookfield 1970; Wasson *et al.* 1988), though it is not established whether all the sectors of the pattern were formed by winds related to one and the same atmospheric system or that they were ever active at the same time. The Australian desert dunes are characteristically long, parallel sand ridges extending unbroken over tens and even a few hundreds of kilometres. Many are asymmetrical in cross-section and display tuning fork or Y junctions. They are generally restricted to the desert plains (Madigan 1936, 1946; Wopfner & Twidale 1967).

Although the precise mechanism of formation is debated, and it is likely that the dunes originate in various ways (McKee & Tibbetts 1964; Wopfner & Twidale 1967; Brookfield 1970; Tsoar 1989; Tseo 1993), some are apparently initiated in the lee of lunettes or other accumulations of sand (Twidale 1972) and extend in a downwind direction. There is a mild controversy as to whether the sand of which the dunes are built is of local derivation (Folk 1971; Wasson 1983) or whether it is essentially exotic and far-travelled (Wopfner & Twidale 1967). The Gawler Ranges dunefields yield evidence germane to this problem.

Immediately to the W of the Gawler Ranges the linear sand ridges of the Great Victoria Desert, the southern part of the great Australian dune pattern, trend WNW to ESE and there are zones of parabolic dunes. Within the Gawler Ranges province the sand dunes are more varied and lunettes, transverse dunes, and climbing and falling dunes, as well as linear and

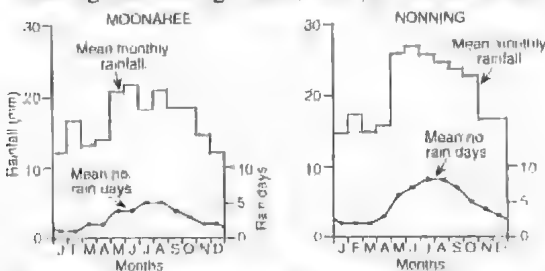


Fig. 2a. Mean monthly rainfall and mean number of rain days for Moonaree and Nonning (Bureau of Meteorology 1993a). Length of record: Moonaree - 108 years, Nonning - 90 years.

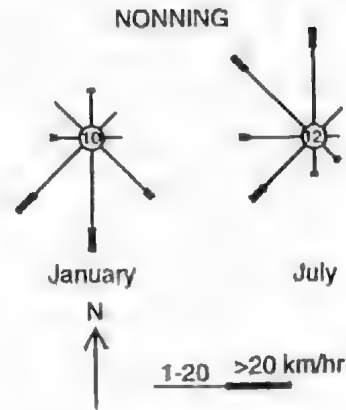


Fig. 2b. Nonning wind data (Bureau of Meteorology 1993b). The percentage of calm observations is indicated in the centre of the rose. Length of record 23 years.

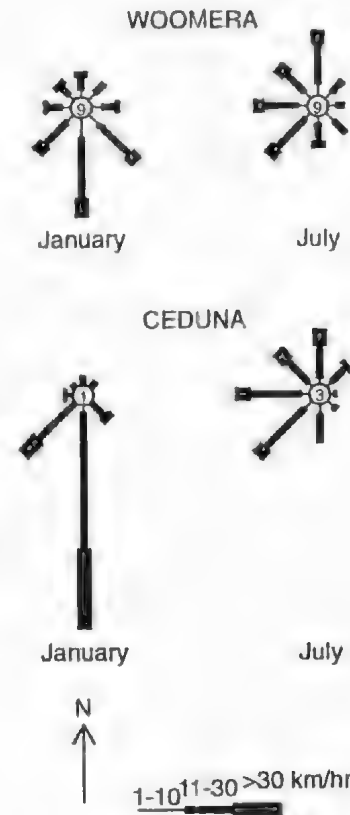


Fig. 2c. Wind roses for Woomera and Ceduna (Bureau of Meteorology 1988). The percentage of calm observations is indicated in the centre of the rose.

parabolic dunes, are developed. Some are stable, but others are occasionally mobile.

Three fields of dunes penetrate the uplands (Fig. 1b). In the N, the Hiern Dunefield extends WNW to ESE between the Kokatha hills and Lake Everard to the western shore of Lake Gairdner. The dunes are predominantly linear forms. Dunes also occur N of the Ranges and also on some of the islands within Lake Gairdner. In the same latitude, and to the lee of a major lunette developed on the E shore of Lake Gairdner, the Piccadilly Dunefield extends eastwards for 35 km across the plains located between Lake Gairdner and Island Lagoon. Here linear sand ridges and parabolic forms are well developed and some lunettes occur on the eastern margin of small salinas.

The Moonaree Dunefield occupies the plain between the volcanic Everard hills to the N and the granitic Kondoolka hills to the S and extends eastwards to Lake Acraman. In this part of the Moonaree Dunefield there is a sharp boundary between parabolic dunes to the S and linear sand ridges to the N. Dunes occur on islands within Lake Acraman and on its eastern shore. To the NE of Lake Acraman the plain carries a veneer of sand but dune forms are absent. Further to the E, however, linear sand ridges are again developed and extend as far as the shore of Lake Gairdner. Immediately to the W of this salina, some of the dunes

override the low volcanic hills forming climbing and falling dunes. The Beacon Dunefield (the Black Oak dunefield of Smith 1976²) extends eastwards from the E shore of Lake Gairdner, again in the lee of a major lunette. This field consists mainly of linear sand ridges but there are some lunettes and parabolic forms.

The most southerly dunefield, the Ilkina Dunefield, is part of the Kododo Dunefield of Smith (1976²). Both the field and individual dunes trend NW to SE between the Corrobinnie Depression (Bourne *et al.* 1974; Binks & Hooper 1984) and the SW margin of the Gawler Ranges from near Yarranna Hill to the vicinity of Mt Sturt. Within the Corrobinnie Depression, complex parabolic forms are well developed. In the vicinity of Mt Centre, linear sand ridges from the Ilkina Dunefield diverge ESE and extend across narrow plains and valleys between the volcanic uplands and extend into the hilly areas to form the Scrubby Peak Dunefield (Fig. 1b). In both the N and S arms of this dunefield there are departures from the general ESE trend as a result of topographic interference with the airflow. Both crestal transverse dunes and climbing and falling dunes result from such topographic effects.

Dune morphology

Linear dunes

Linear sand ridges dominate the dunefields within the Gawler Ranges (Fig. 3). These linear forms trend WNW to ESE in the W and latitudinally further to the

²SMITH, D. M. (1976) The denudation chronology of the southern Gawler Ranges and adjacent areas. MA thesis, University of Adelaide (Unpub.)



Fig. 3. Linear sand ridges of the Scrubby Peak Dunefield funnelled along broad valleys between the bornhardts of the southern Gawler Ranges, South Australia. Field of view in foreground approximately 5 km.

E. In places, e.g. near Mt Granite (Fig. 4), funnelling of the wind has produced dunes aligned at various angles to the regional trend. The linear dunes vary in height, length and linear frequency, i.e. the number of sand ridges per unit distance measured normal to the dune trend. The maximum height of the dunes varies from 5–15 m above the interdune corridors. They vary in length from a few tens of metres up to 20 km; none extends unbroken for many scores or hundreds of kilometres as do some of the sand ridges of desert plains such as the Simpson Desert (Wopner & Twidale 1967, 1990; Twidale 1981). The linear frequency of the dunes varies between two and six per km. The interdune corridors are sand covered. Most of the dunes are symmetrical, with smooth crests which rise and fall to form peaks and saddles. The slopes are gentle, considerably less than the angle of repose of the sand. No depositional structures and no slip faces have been noted. The dunes carry a covering of low shrubs and small trees, though little or no soil development is apparent and there is, today, only occasional and minor reworking of the sand by wind and water. The dunes are relic according to the classification of Livingstone & Thomas (1993).

Parabolic dunes

Groups of parabolic or U-dunes occur within the linear dunefields. Most of the parabolic dunes occur outside the Ranges, and notably in the Corrobionie Depression (Bourne *et al.* 1974), though there is a W-E zone within the Moonaree Dunefield and patches

of parabolic forms occur within the Piccadilly and Beacon dunefields. Although many of these dunes are complex in plan form, with transverse, rake-like and circular patterns well developed, the basic unit is a U-shaped dune about 8 m high and with the open end of the U pointing to the W (Fig. 5).

Climbing and falling dunes

In the Gawler Ranges most of the dunes are developed on broad valley floors between the bornhardts. In some areas, however, linear dunes penetrate into the hilly terrain and suffer modification as a result of funnelling and diversion of the wind (Fig. 4). In other areas, the dunes extend over the bornhardts. On the reasonable assumption that the sand migrated southeastwards, dunes piled against the windward (northwestern) slope of a hill are termed climbing, or rising, dunes; where sand has overridden the crest of a hill and extended on to the leeward (southeastern) slope, falling, or hanging, dunes are formed (Fig. 6a).

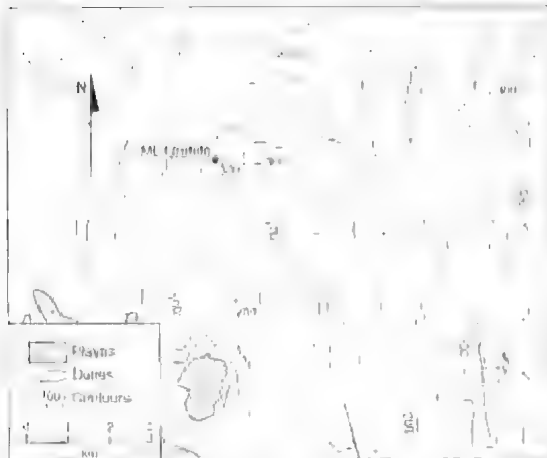


Fig. 4. Schematic diagram of linear dunes oriented NW to SE, and irregular patterns of linear and transverse dunes due to topographic interference to the wind near Mt Granite, Gawler Ranges, South Australia (from aerial photographs, Department of Lands, South Australia and 1:100 000 National topographic map series). Not all dunes are shown.

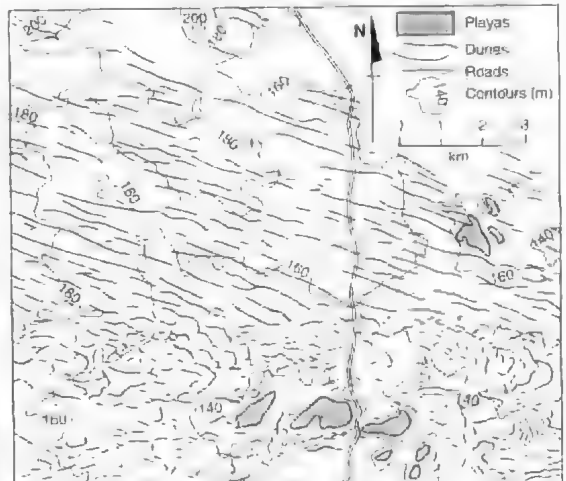


Fig. 5. Linear and parabolic dunes of the Moonaree Dunefield 15 km south of Lake Everard H.S. (from aerial photographs Department of Lands, South Australia and 1:100 000 National topographic map series).



Fig. 6a. Echo, climbing and falling dunes (after Mabbutt 1977). Arrow indicates direction of the wind. A. Linear dune not anchored by topography. B. Linear dune rising over topographic obstacle. C. Climbing (1) and falling (2) dune. D. Echo dune.

These dunes have not been studied in detail in the arid mountains of Australia, although dunes which arguably ascend cliffs have been studied in the coastal context (Jennings 1957; Langford-Smith & Thom 1969).

Climbing and falling dunes are known from various parts of the world, for example from periglacial Finnish Lapland (Seppälä 1993), coastal west Galicia, Spain and NE Spain (Crós & Serra 1993), but most previously published reports pertain to warm desert environments, e.g. California (Evans 1962; Smith 1967 cited by Bender 1982; Anders 1974 cited by Bender 1982; Lancaster 1994), Colorado (Johnson 1968), Idaho (Koscielniak 1973³), Arizona (Greely & Iverson 1985) and Utah (Alhbrandt 1979), all in the United States, where most are inactive, veneered by gravel and dissected by ephemeral streams (Smith 1982), northern Mexico (Stone 1967), Brazil (Bigarella 1975, 1979), Egypt and Jordan (McKee 1979), the Sinai Peninsula (Alhbrandt 1979), the Sahara (Smith 1954) and the central Namib Desert (Goudie 1972). They are also found in the eastern Flinders Ranges, South Australia (Green 1994⁴), near Port Stephens and in the Shoalhaven River area in New South Wales (Thom *et al.*, 1994), on the Eridunda Range 160 km south of Alice Springs and on the northern margin of the Simpson Desert where dunes override some of the latitudinal ranges. Greeley (1985, Fig. 7.39) illustrates a field of climbing dunes drifting over the rim of a 16 km diameter crater on Mars.

In the Gawler Ranges climbing and falling dunes occur in three areas. First, examples were noted by Smith in the Scrubby Peak Dunefield (1976²; Fig. 6b, c). Second, Giles (1980⁵) remarked that sand dunes encroach on to the slopes of Mt Sturt. Sand from the Ilkika Dunefield has accumulated on the NW slopes of Mt Sturt (the western peak) and forms an irregular mound along the base on its SE side. Third, climbing and falling dunes are common in the Moonaree Dunefield E of Lake Acraman, where small dunes trending W-E are essentially restricted to the plains, though they partially override many of the bornhardts (Fig. 6d).

In the Scrubby Peak Dunefield, some linear dunes have been diverted around the major volcanic hills (Figs 4, 6b,c) but elsewhere, especially where the relief is lower, the dunes traverse hill and valley alike. The dunes ascend the lower hills (in general terms those that stand less than some 40 m above the adjacent valley floors) without significant interruption of form and are

classified as climbing dunes. In some instances the dune is diverted around the flanks of the hill and continues downwind (Fig. 6b). Elsewhere, the dune form is interrupted, for although there are many grains and even small pockets of sand in fissures and shallow rock basins on the crests and upper slopes of the hills, there is no dune form; a short distance downslope from the crest, however, the dune form is resumed in falling dunes 3–4 m high (Fig. 6c).

Transverse dunes

In the Scrubby Peak Dunefield funneling of the wind has produced dunes of varied orientation. In this part of the Gawler Ranges elongate bornhardts are aligned essentially N-S. Sand ridges also aligned N-S are located in the valleys between the bornhardts. There are some W-E dunes which override the bornhardts and, in addition, N-S trending elongate dunes are located just below the crest on the lee side of these hills (Figs 4, 7). These crestal dunes are tentatively classified as of transverse type.

Lunettes

Lunettes are developed along at least part of the E side of most of the large salinas and many of the smaller playas in the region (Fig. 1c). Lunettes are transverse dunes located on the lee shores of lake basins. The name 'lunette' was first applied to the form by Hills

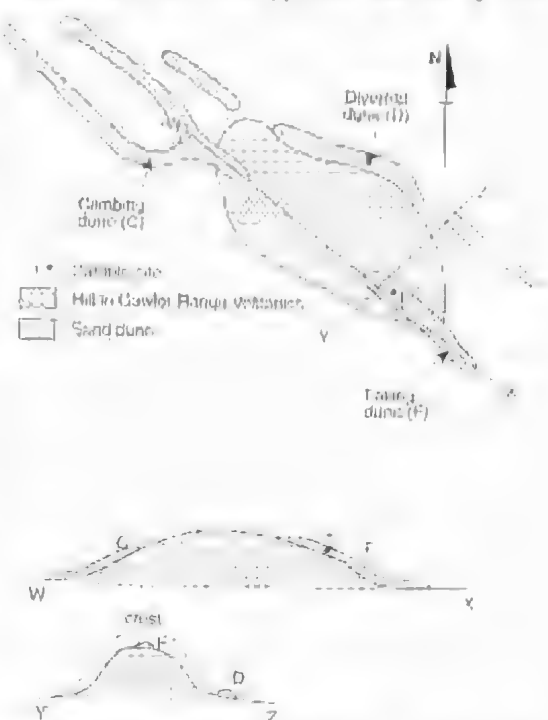


Fig. 6b. Scrubby Peak area, Gawler Ranges, South Australia, showing diverted dune (D), climbing dune (C) and falling dune (F) (from 1:100 000 National topographic map series). The dune-forming winds were from the northwest sector.

³KOSCIELNIAK, D. E. (1973) Eolian deposits on a volcanic terrain near Saint Anthony, Idaho. MA thesis, University of New York (Unpub.)

⁴GREENE, S. J. (1994) A geomorphological and sedimentological study of a climbing dune, northern Flinders Ranges, South Australia. BA (Hons) thesis, University of Adelaide (Unpub.)

⁵GILES, C. W. (1980) Spring Hill, southern Gawler Ranges. Geol. Soc. Aust. S. A., Div. Geological Monuments III, File E 20 (Unpub.)

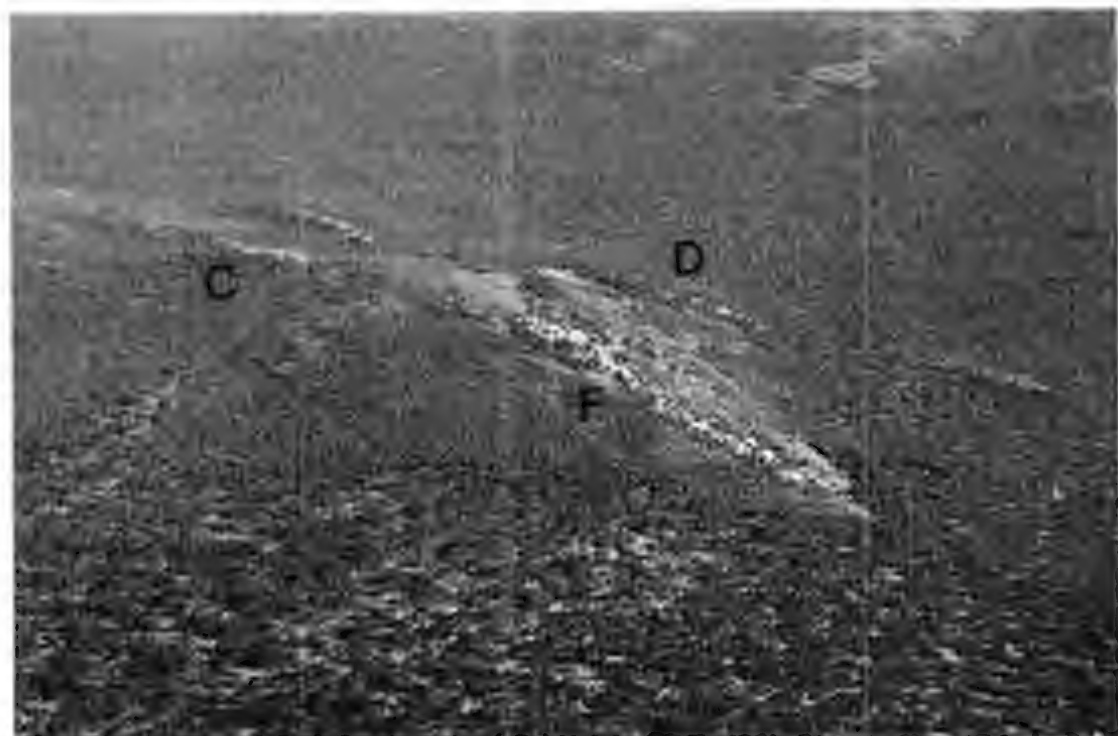


Fig. 6c. Deverned dune (D), climbing dune (C) and falling dune (F). Scrubby Peak area, Gawler Ranges, South Australia. View to the north. The hill stands about 25 m above the surrounding plain.



Fig. 6d. Climbing and falling dunes, Moosarem Dune-field, Gawler Ranges, South Australia. Note that the falling dune, on the near side of the horizon, occurs in a topographic embayment. Field of view approximately 2 km.

(1940) who described lunettes of silty-clay compositions from NW Victoria. Subsequently, lunettes of various sizes and mineralogies have been reported from all states of Australia. They range in composition from quartz-rich to clay-rich to almost pure gypsum. The sandy quartz-rich dunes were formed by deflation from beaches on the lake margin. The clay-rich dunes were derived by deflation of clay aggregates from the saline lake floors. The gypsum dunes are composed either of rounded crystals deflated from the dry lake bed or of fine 'kopi', some of which may be due to weathering of saltated particles since deposition (Stephens & Crocker 1946; Campbell 1968; Bowler 1968, 1983; Chen *et al.* 1991).

In the Gawler Ranges area lunettes of gypseous composition occur on the eastern margin of lakes Everard, Harris, Acraman and of many of the smaller salinas. Both gypseous and siliceous lunettes are found on the eastern side of Lake Gairdner. The most prominent siliceous lunettes are located opposite the dunefields which impinge on the W side of the lake. Both dunefields found E of Lake Gairdner, the Piccadilly and the Beacon, are developed in the lee of these prominent siliceous lunettes. The lunette on the NE margin of Lake Gairdner rises about 35 m above the lake bed. Much of the surface is bare and

erosion by wind and water has created a series of domical remnants, standing 3-4 m above gentle swales. In addition, lunettes consisting predominantly of fragments of Gawler Range Volcanics of sand size occur discontinuously along the margin of Lake Gairdner (Fig. 1c).

Sedimentology

A total of 16 sand samples, each from the crest of a dune, and including at least one from each of the dunefields in the Gawler Ranges province, was examined to determine composition and grain morphology (Table 1) and grain size and related parameters were determined using 0.5 phi standard sieves.

The sand samples are all various shades of yellow-red (2.5 to 10 YR Munsell Soil Colours). All samples consist of at least 90%, and most more than 98%, quartz grains. The minor constituents are quartz rock, feldspar, Gawler Range Volcanics fragments, iron oxide and organic matter. In most samples the grains are predominantly frosted, but some are polished. Samples from two dunes in the Scrubby Peak Dunefield show higher percentages of polished grains. Grains from all samples show ferruginous coatings of yellow

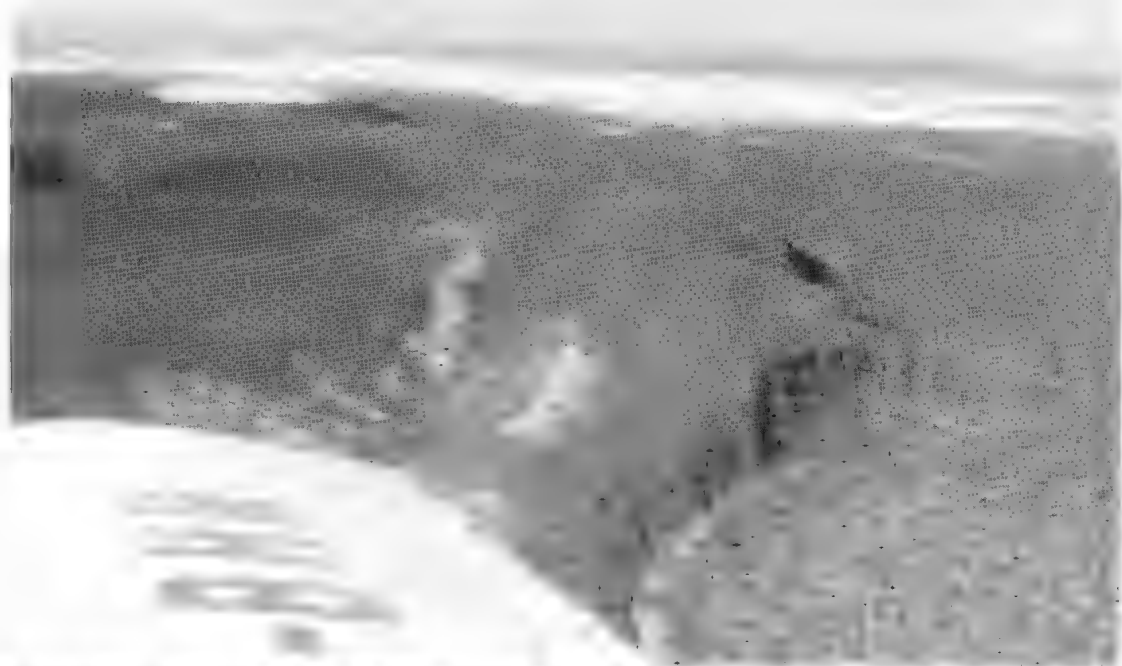


Fig. 7. Transverse crestal dune, Scrubby Peak Dunefield, Gawler Ranges, South Australia. View to the south to the Cornbarbie Depression. The crestal dune is about 8 m high.

TABLE 1. *Composition and grain morphology of samples from dunefields in the Gawler Ranges, South Australia.*

Sample	Dune type	Colour ¹	Composition ²	Surface texture ³	Surface coating ⁴	Roundness ⁵	Sphericity
Beacon Dunefield							
1	linear	2.5YR 5/6	quartz 95% (1,2,3,4,5)	85% MF 15% P	Y, O, R, B.	SR-SA, few R	high, some elongate
Piccadilly Dunefield							
2	linear	5YR 4/6	quartz 99% (1,2,4,5)	98% MF few P	Y, O	SA-SR, few R	high, some elongate
3	parabolic	5YR 5/6	quartz 99% (4,5)	98% MF few P	Y, O	SA-SR, few R, WR	high, some elongate
4	linear	2.5YR 4/8	quartz 99% (4,5)	95% MF few LF few P	Y, O, R	SA-SR, few R	high, some elongate
5	linear	2.5YR 4/8	quartz 98% (1,5)	98% MF 2% P	Y, R, B	SA-SR, few R	high, some elongate
Hiern Dunefield							
6	linear	5YR 5/6	quartz 99% (1,4,5)	98% F 2% P	Y, O	SA-SR, few WR	high, some elongate
7	irregular	5YR 5/6	quartz 99% (4,5)	95% F 5% P	Y, O	SA-SR, few R	high, some elongate
8	linear	7.5YR 6/6	quartz 99% (1,4,5)	95% MF 5% P	Y, O	SA-SR, few R, WR	high, some elongate
9	linear	5YR 5/8	quartz 90% (1,3,4,5)	90% F 10% P	Y, O	SA-SR, some R	moderate, some high
Moonaree Dunefield							
10	linear	7.5YR 5/6	quartz 98% (1,4,5)	90% LF 10% P	Y, O	SA-SR, some A, R	high, some elongate
11	irregular	7.5YR 5/6	quartz 99% (4,5)	95% F 5% P	Y, O	SA-R, few WR	high, some elongate
Scrubby Peak Dunefield							
12	linear	7.5YR 5/6	quartz 95% (1,4,5)	95% MF 5% P	Y, R, B	SA-SR, few R, WR	high, some elongate
13	linear	10YR 5/4	quartz 99% (1,4,5)	70% MP 30% SF	Y, O, B	SA-SR, some R	high-moderate, some elongate
14	linear	10YR 6/4	quartz 99% (1,4,5)	50% P 50% F	Y, O	SA-SR, few R	high-moderate, some elongate
15	linear	7.5YR 4/6	quartz 98% (1,4,5)	98% F 2% P	Y, O	SA-SR, few A, R	high-moderate, some elongate
Ilkina Dunefield							
16	linear	7.5YR 6/6	quartz 98% (1,3,4)	70% LF 30% P	Y, O, R	SA-SR, few R	moderate-high, some elongate

¹Munsell Soil colours.²Minor constituents in brackets: 1: quartz rock, 2: feldspar, 3: Gawler Range Volcanics, 4: iron oxide, 5: organic material.³F: frosted, P: polished, M: moderately, L: lightly.⁴Y: yellow, O: orange, R: red, B: brown.⁵SA: subangular, SR: subrounded, A: angular, R: rounded, WR: well rounded

and less commonly orange, red and brown, material. The grains in all samples are predominantly subangular to subrounded, with small amounts of angular and well-rounded grains. High to moderate sphericity is characteristic, with most samples containing some elongate grains.

The dune samples are all fine to medium grained sands (mainly 0.125 to 0.5 mm diameter - Folk 1968). They are well-sorted to poorly sorted, with most samples moderately well-sorted.

Age of the dunes

The sand of the Gawler Ranges dunes is typically a yellow-red colour (Table 1), suggesting sufficient time for initial weathering of clay, release of iron, and development of a faint ferruginous patina. The sand is not the brilliant red of the deserts of central Australia, nor the dusky red (10R 3/4 Munsell Soil Colour) of the sand derived from the local Gawler Range Volcanics. Some authors would attribute the contrasting

colour to different source materials (Wasson 1983; Nanson *et al.* 1992). Others, e.g. Wopfner & Twidale (1967) and Walker (1979) consider that the intensity of the red colour increases with time and hence is an indication of the age of the dune.

In an attempt to attain a more precise estimate of age, sand from the Scrubby Peak Dunefield was tested for thermoluminescence (TL). Samples were taken from a falling dune on an unnamed hill (National Topographic Map Series Minnipa 5932, 1:100 000, Grid Reference NE316018) 1.5 km E of Scrubby Peak (Fig. 6b). The method was a variation on the "partial bleach" method developed for the TL dating of sediments by Wintle and Huntley (1982). The age is estimated by measuring the TL energy stored in the lattice of a suitable mineral, in this case, quartz. The time interval measured is the time since the stored energy was last reset to zero or near zero by exposure to solar ultra-violet radiation. After such a re-setting, energy accumulates again at a known rate by exposure to radiation in the environment from the naturally radioactive elements K, U, Th and from cosmic rays. The age is found from the so-called age equation:

$$\text{age} = \text{natural TL}$$

$$\text{TL per unit dose} \times \text{dose rate}.$$

Samples were recovered from depths of 35 and 70 cm within the dune by means of an auger, taking care to shield the sample from light during and after collection. After digestion with 20% HCl to remove carbonates and NaOH to remove clay, the 90–125 μm fraction was recovered by sieving. A 40 minute etch with 40% HF removed feldspars and a surface layer of the quartz. Flotation on aqueous sodium polytungstate at a relative density of 2.67 followed; the end product was very pure quartz and it is on this sample that the measurements were carried out.

One of the problems with TL dating of sediments is uncertainty about the degree to which the TL was reset at the beginning of the time of interest. It is rare for the TL to be removed completely, even by prolonged exposure to sunlight. Moreover, the amount of re-set TL varies from sample to sample and may vary with the age of the sample (Berger 1990). In the present investigation, it was found that the accumulated TL was small so that any uncertainty in the degree of resetting would result in significant uncertainty in the age. The level of resetting was found from a surface sample collected by pressing packing tape against the exposed dune surface. This showed that the TL clock had not been completely reset to zero in spite of the long time likely to have been spent in the sun by the sample in reaching its present position. Under these circumstances special procedures are necessary, as described by Prescott & Mojarrahi (1993). They make

use of the fact that many quartz samples have a so-called "rapidly bleaching" peak (RBP) at 325°C in the thermoluminescence glow curves, which bleaches to near zero within a matter of minutes when exposed to light of wavelength longer than about 500 nm (Spooner *et al.* 1988). This means that exposures of the order of minutes to natural sunlight in the environment will have ensured that the trap concerned had been emptied completely and that, at least so far as the 325°C peak is concerned, the TL clock of the sediment was completely reset at the time of deposition. In addition, this peak emits in a wavelength band centred near 420 nm, so that an optical filter transmitting this band will be selective for the peak in question (Prescott & Fox 1990; Schofield *et al.* 1994). The 325°C peak rides on an unbleached background, which is measured and allowed for by the procedures. The surface sample mentioned above had zero TL when measured with the revised procedures.

The TL is expressed in terms of an equivalent dose measured in grays (Gy). The equivalent doses are: for the 35 cm sample 1.24 ± 0.20 Gy; and for the 70 cm sample 1.53 ± 0.25 Gy. The dose rate has been measured by three essentially independent methods (Hutton & Prescott 1992). They are, with the relevant dose rates in brackets: *in situ* gamma ray spectrometry (0.153 ± 0.028 Gy ka⁻¹); thick source alpha counting for U and Th with X-ray spectrometry (XRS) for K (0.142 ± 0.029 Gy ka⁻¹); and delayed neutron analysis (DNA) for U, neutron activation analysis (NAA) for Th with XRS for K (0.168 ± 0.041 Gy ka⁻¹). The weighted average is 0.152 ± 0.010 Gy ka⁻¹ for both the 35 cm and 70 cm samples.

Contributions for cosmic rays must be included. These are 0.21 ± 0.02 and 0.18 ± 0.02 Gy ka⁻¹ for the 35 and 70 cm samples respectively (Prescott & Hutton 1988, 1994). It is worth noting that cosmic rays dominate the dose rate because the levels of K, U and Th are so extremely low (K - $0.04 \pm 0.01\%$; U - 0.22 ± 0.06 ppm; Th - 1.0 ± 0.4 ppm). Over the time in question, changes in cosmic ray intensities are negligible (Prescott & Hutton 1994).

The dose rates are 0.35 ± 0.03 Gy ka⁻¹ at 35 cm and 0.33 ± 0.03 Gy ka⁻¹ at 70 cm. A contribution from systematic errors has been added. Hence, the age of the 35 cm sample is 3.7 ± 0.7 ka and of the 70 cm sample 4.6 ± 0.9 ka. Although the deeper sample has the greater TL age, the two ages are not statistically different and probably all that can be concluded is that the dune has been in place for about 4 ka.

This age is based on a single series of dates from one dune. Obviously, more age determinations are required. Nevertheless, the pale colour of the sand, to which previous reference has been made, and the lack of any carbonate accumulations in the dunes (despite its availability) are suggestive of a youthful age.

The general appearances are consistent with the TL dating in suggesting that the Gawler Ranges dunes are younger than the putative Late Pleistocene relic forms of NW Eyre Peninsula (Twidale *et al.* 1976) and are comparable to the Holocene forms of that area (Rankin & Flint 1991) and of the Simpson Desert (Wopfner & Twidale 1988, 1990). Nevertheless, the age determination obtained is for the uppermost layers of a dune and there is no evidence of the age of the sand at the base of the dune.

Origin of the dune sand

As mentioned previously, the provenance of the sand in dunefields, whether it is of local derivation or far-travelled, is controversial. The question can be clarified by a consideration of the sedimentologic characteristics of the dune and other sands. In the Gawler Ranges province, a local origin of the dune sands is precluded by their composition and granulometry as set out in Table 1. For example, the Scrubby Peak Dunefield overlies outcrops of Eucarro Dacite, and Yardea Dacite, with small areas of Yannabie Rhyodacite, Paney Rhyolite and, at the base of the Yardea Dacite, 'black' dacite (Blissett *et al.* 1988, Fig. 8). The microscopic groundmass of the volcanic rocks is rich in quartz, but the grains are much smaller than those of the dune sands. There are no quartz phenocrysts in the dacite (Blissett 1986). No quartz of a size equal to, or greater than, that of which the Scrubby Peak dunes are composed (and hence susceptible to attrition to produce sand-sized grains) could be derived from the Yardea and Eucarro dacites which are the country rocks over which, overwhelmingly, the dunefields have extended. No lakes or streams which might constitute a possible source of sand in the dunes are known from within the province.

If it is accepted that the dunes of the Scrubby Peak and other dunefields of the western Gawler Ranges extended from the W or NW, then there are three other possible sources of the quartz sand.

First, there are outcrops in the western Gawler Ranges of Yannabie Rhyodacite and of Paney Rhyolite (Fig. 8), both of which contain phenocrysts of quartz of a size equal to, or greater than, the dune sand (0.2 to 2.0 mm in diameter - Blissett 1986). Similarly, and second, granite with abundant coarse quartz crystals crops out to the west of the Ranges (Blissett *et al.* 1988). But difficulties attach to these outcrops as sources of the dune sand: they are of limited extent (about 60 km² compared with the 300 km² of the Scrubby Peak Dunefield); and it can be questioned whether they could produce a volume of quartz sand compatible with that represented by the total of the dunes. Also the outcrops do not extend across the width of the dunefield, so that the spread of sand from them

calls for varied strong winds, and for distribution in topographically difficult terrain. Moreover, the dunefield extends westwards, i.e. windwards, of the outcrops in question (Fig. 8). Against these arguments, the Gawler Range Volcanics form a regional basin structure so that before erosion to their present occurrences, the quartz-bearing members could have extended further to the W. In addition, the former shape and size of these members could have been very different from their present representatives. But, on the evidence, the rhyodacite, rhyolite and granite outcrops of the western ranges and adjacent areas do not seem likely sources of suitable quartz sand.

The third possibility is that the dune sand has been derived from the Corrobinnie Depression. This runs in a NW-SE direction west, and therefore windward, of the dunefield and contains detritus derived from the granite areas to the S, W and N as well as from the Gawler Ranges. It contains quartz comparable in size and character to the dune sand of the Scrubby Peak Dunefield (fine-grained, moderately well sorted, typically subrounded, frosted and coated with iron oxide - Gostin pers. comm. 1993). It is concluded that the dune sands of the Scrubby Peak Dunefield cannot have been derived from the disintegration of the Gawler Range Volcanics, but rather have been transported on the wind from the Corrobinnie Depression, a distance of at least 30 km. Even if derived from the rhyolite, rhyodacite and granitic outcrops, the sand must have travelled 25 km to cross the zone of dacitic bedrock. Given the wind regime, the northern arm of the Scrubby Peak Dunefield (X in Fig. 8) could only have

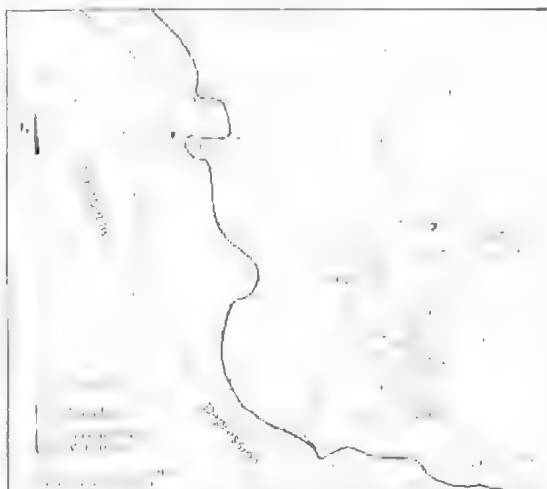


Fig. 8. Scrubby Peak Dunefield, western Gawler Ranges, South Australia, illustrating bedrock type and possible sources of the dune sand. X, Northern arm of the Dunefield. Y, Nearest upwind outcrop of rhyolite/rhyodacite. ED, Eucarro Dacite. YD, Yardea Dacite. R, Rhyolite. RD, Rhyodacite. See text for explanation. After Blissett *et al.* 1988.

originated in the rhyolitic/granitic outcrops indicated by Y in Fig. 8, or from outcrops further westward. Whether this would be considered far-travelled is a matter of definition, but the sand is certainly not of local derivation.

Mechanism of dune formation

Prevailing winds

It is suggested (see below) that the dunefields of the Gawler Ranges have been shaped by winds from the western sector. This is consistent with the putative source of the sand of which the dunes are constructed (see below). The relic linear dunes to the south of the Gawler Ranges, which possibly formed in late Pleistocene times, extended from NW to SE across the northern base of Eyre Peninsula, for they extend on to the western shores of salinas such as Lake Agars, but not on to the eastern shores (Twidale & Campbell 1985). These NW-SE dunes also extend well below low tide level between Cowell and Whyalla (Van Deur 1983⁶) but only in minor degree on the eastern side of the Gulf on northwestern Yorke Peninsula, where the aeolian forms were deposited during a phase of rising sea level and where the dunes are truncated by wave action at the coast (Jessup 1967, 1968). This is consistent with a wind regime dominated by north-westerlies.

In addition, at Lake Gairdner, the lunettes of the eastern shore are much more substantial than those of the western and, as the lunettes are comparable to coastal foredunes (Campbell 1968), this supports a westerly wind regime. Also, the huge Late Pleistocene calcareous aeolianite foredunes of west-facing shores in South Australia (e.g. on Eyre Peninsula) dwarf their east coast counterparts. Thus, there is evidence of a predominantly westerly wind regime in the Gawler Ranges and surrounding areas during the period, or periods, of dune formation.

There is, however, an anomaly between the present wind regime, as illustrated by the wind rose for Nonning (Fig. 2b) and the presumed westerly wind of dune formation, since the winter sand-moving winds blow from the westerly sector, whereas the summer sand-moving winds are from the SW, S and SE. It is presumed that most of the sand movement would take place in summer under hot and dry conditions, with only minor transport in the moist, cool and vegetated winter conditions. But, if there were only a slight latitudinal migration of climatic zones during the period of formation of the dunes, as suggested for example by Mabbutt (1977) and Sprigg (1979), then the region

would have been influenced by summer rainfall maxima which would reduce sand movement during that season. On the other hand, dry winter conditions would be suitable for the evidenced transport of sand by westerly winds. The lack of compatibility between dune orientation and wind direction remains a problem.

But assuming a westerly wind regime, what factors are important in the formation of linear dunes? Why do parabolic dunes develop? How do the climbing and falling dunes form, and why do some of these forms continue across the crests of the hills, whereas others terminate on the upwind side only to resume on the lee slope? How are the transverse dunes formed?

Linear dunes

The origin of linear dunes is still debated (Cooke *et al.* 1993). Where the dunes have been closely examined, as in the Simpson Desert, these sand ridges appear to display the same range of morphology, and internal structures and temporal variations in asymmetry, indicative of formation under a bidirectional wind regime (McKee & Tibbetts 1964; Wopfner & Twidale 1967; Brookfield 1970; Tsoo 1990, 1993). The linear dunes of the Gawler Ranges, however, developed in an upland setting rather than on desert plains. The confined valleys ought, in theory, to funnel the wind and hence to be conducive to a unidirectional wind regime, but bidirectional winds could be either dominant or be superimposed on unidirectional effects. No structures have been observed within the dunes and, though this may reflect absence of deep exposures as much as any diagnostic factor, it is not possible to state whether the dunes have been shaped under a unidirectional or a bidirectional wind regime.

Judging from the orientation of the linear dunes in the Gawler Ranges, the airflow was apparently disturbed by the hills of the province and was funnelled along valleys. The hills induce zones of increased and of decreased air flow and of enhanced turbulence. The dunes that are diverted around flanks of hills also reflect topographic control of the wind. The changes in dune orientation and morphology between, on the one hand, the Great Victoria Desert, and, on the other, the Gawler Ranges, are due to several factors. First, the westerly winds are diverted along the valleys. The linear dunes are not everywhere parallel with the regional air flow, as is characteristic of dunefields on plains but their orientation is, in part, determined by the local wind regime. Second, sand supply decreases within the upland where the silicic volcanic rocks weather less readily than do the granites to the west and, in particular, the supply of quartz grains is reduced. Third, sand movement is impeded as a result of the presence of near surface moisture, held either in valley alluvium or in rock fractures, and consequent vegetation growth.

⁶ VAN DEUR, W. I. (1983) Submerged dunes of northeastern Eyre Peninsula. MA thesis, University of Adelaide (Unpub.).

Because of the lack of observed structures in the dunes, the uncertainty about the relationship between dune morphology and wind regime and the fact that the dunes are relic and possibly related to different wind velocities, wind directions and rainfall amounts and distributions, the classification of the dunes as linear, i.e. elongate forms aligned in the direction of the dominant sand moving winds, is tentative.

Parabolic dunes

The occurrence of parabolic rather than linear dunes, can be explained as follows. In the Corrobinnie Depression to the S of the Gawler Ranges (Bourne *et al.* 1974) and elsewhere (McKee 1966; Wasson *et al.* 1983) parabolic dunes are located in low-lying areas characterised by an abundant supply of sand and by proximity to groundwaters, which leads to the lower parts of the dune being stabilised by moisture and vegetation. This allows the higher zones of sand to be transported downwind to give blowouts or U-dunes. In the Gawler Ranges area the parabolic dunes occur only in wide open valleys and on plains, for example in the western Moonaree Dunefield and in patches in the Piccadilly Dunefield. However, they are not necessarily restricted to the lowest parts of these valleys. On the available evidence and as indicated on the 1:100 000 topographic map with a contour interval of 20 m, the W-E belt of parabolic dunes in the Moonaree Dunefield is sharply delimited on the northern side by a belt of linear dunes and, less sharply, on the southern side by dune-free plains. The parabolic dunes override low N-S rises in the valley and linear dunes occupy some low-lying areas in the northern part of the dunefield. Thus, in addition to stabilisation by vegetation and an abundant supply of sand, parabolic dune formation may require a critical wind velocity such as is attained only in wide valleys and on plains.

Climbing and falling dunes

The climbing and falling dunes are a particular variety of linear dune which rise and descend topographic obstructions where the local wind is strong enough to carry the available sand grains up and over the topographic rises. The wind velocity is apparently reduced on approaching the obstacle and deposition of sand occurs. Many of the bounding slopes of the bornhardts are gentle (about $5-12^\circ$) and reverse eddy flow is generally not developed, and hence echo dunes (Tsoar 1983; see also Fig. 6a) are not found windward of cliffed obstacles. Where the supply is sufficient, sand accumulates until the dune reaches the height of the obstruction. Where the bornhardt is low (in the Gawler Ranges <40 m) the dune extends on to and over the crest as a climbing and falling dune. Where the bornhardt is high (>40 m), the dune form may be discontinuous though sand is carried on to the crest, as evidenced by grains trapped in basins and crevices.

Downwind of the obstacle, however, there is a zone of reduced wind velocity and sand deposition and dune formation occur. There may be further funnelling of the sand to the lee of the obstacle where the falling dune is resumed in a topographic embayment (Fig. 6d). The contrast between those linear forms that continue unbroken over crests of bedrock hills and those in which the climbing and falling components are separated, evidently reflects the Bernoulli effect (Pye & Tsoar 1990).

Transverse dunes

The transverse dunes of the Scrubby Peak Dunefield occur immediately downwind of the Corrobinnie Depression, the presumed source of the sand, and where the sand supply is abundant. The bornhardts in this area stand about 100 m above the level of the plain, form N-S trending ridges and the bounding slopes are generally $5-10^\circ$ with some as steep as 18° . The plain is sand covered, with linear dunes of varied orientation, but generally NW-SE, where there are no topographic obstacles; N-S in the valleys and W-E on the bornhardt rises (Fig. 4). Some of the N-S linear dunes override topographic obstacles and hence are classed as climbing and falling dunes. The W-E transport of sand across the bornhardt rises also explains the presence of sand in the valleys. However, some of the dunes are limited to the upper slopes of the bornhardts and are located immediately to the lee of the crest of the bornhardts (Fig. 7). Although they may be linear dunes formed by winds from a northerly or southerly direction, in which case they do not conform to the pattern of dunes throughout the region, it is more likely that these crestal dunes are transverse to the originating wind. It is suggested that the sand in these transverse dunes was driven up the windward slope of the bornhardts and little or no deposition occurred here due to acceleration of the air flow. However, immediately downwind of the crest, separation of the air flow and deceleration occurred so that deposition of sand eventuated. However, further downwind, air flow accelerated and no dune formed.

It is suggested that in this area the dunes are a result of two different wind regimes; one a NW-SE wind that was deflected by the topography and one a NW-SE wind that was of sufficient strength to transport sand over the obstacles.

Significance of lunettes and salinas in sand supply

The lunettes located on the eastern shore of Lake Gairdner evidently spawn fields of linear dunes in their lee in a manner similar to that described from the Simpson and other deserts (Twidale 1972, 1981). The transport of sand to the salinas by rivers and the formation of the lunettes are important influences on sand supply and dune formation. Whether sand is carried by the wind from the W to the E shore of Lake

Gairdner (some 30 km) has not been determined. No dunes have been observed on the bed of the lake (J. Andrews, pers. comm. 1994), though small barchanoid forms have been reported on the bed of Lake Harris (R. Major, pers. comm. 1992). Sand could be carried by saltation across the salina. Given the hygroscopic character of the halite crust this may be difficult to conceive, though Clarke (1994) described saltation on some salinas in Western Australia and S. Wells (pers. comm. 1994) has observed grains saltating across a salt surface in California. Alternatively, sand reaching the W shore on the wind could be carried by wave action to the E shore during the occasional periods when there is water in the lake (Campbell 1968), though not from the lake bed unless the salt crust is dissolved or otherwise removed. Small ephemeral salt dunes, noted on the eastern shore of Lake Gairdner, indicate the temporary redistribution of some of the salt by deflation.

Conclusion

More data on the dunes of the Gawler Ranges province are required before firm conclusions can be drawn concerning the origin and age of the various dune forms. The available information suggests that the variations in morphology depend, at least in part, on supply of sand, moisture content of the substrate, vegetation cover, wind speed and direction, and topographic interference to the wind. The suggestion

that the formation of parabolic as opposed to linear dunes is dependent on an abundant supply of sand and fixing of the dune by vegetation only partially explains the distribution of these dune types in the Gawler Ranges province; other factors are apparently involved. Climbing dunes are a variant of linear dunes and form in the zone of reduced wind velocity upwind of an obstacle where the slope of the obstacle is gentle and does not generate reverse eddy flow. Falling dunes are associated with climbing dunes provided the sand supply is sufficient. They develop in the zone of reduced wind velocity to the lee of the obstacle. The crestal transverse dunes are also due to deposition in the zone of reduced wind velocity. Though the dunes of the Gawler Ranges area are essentially relic and are now stabilised by vegetation, there is sand movement during very high winds. The dunes were active about 4000 years BP. The dunes of the Scrubby Peak Dunefield in the southern Gawler Ranges demonstrate that here the sand has been transported by the wind at least 25 km from its source.

Acknowledgments

The authors thank J. A. Bourne for assistance in the field, V. A. Gostin for advice on sedimentology, K. Moxham for advice concerning air flow around obstacles and R. Rice, R. Barrett and S. Proferes for technical assistance. Two referees gave helpful suggestions on an earlier draft of the paper.

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**A REVISED SYSTEMATIC PLACEMENT FOR
AUSTROTROMBELLA SOUTHCOTT
(ACARINA: HYDRYPHANTIDAE)**

*BY MARK S. HARVEY**

Summary

Harvey, M. S. (1996) A revised systematic placement for Austrotrombella Southcott (Acarina: Hydryphantidae). Trans. R. Soc. S. Aust. 120(1), 37-40, 31 May, 1996.

Austrotrombella leprosa Southcott, 1991, is transferred from the Trombellidae (Trombidioidea) to the Hydryphantidae (Hydryphantoidea) and compared with other thysanines of the Panisellus group.

Key Words: Taxonomy, Acarina, Hydryphantidae, Austrotrombella, Trombellidae, South Australia.

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KEY WORDS: Taxonomy, Acarina, Hydryphantidae, *Austrotrombella*, Trombellidae, South Australia.

Introduction

The monotypic genus *Austrotrombella* Southcott, 1991, was recently described from four unusual specimens collected from wet shellgrit and soil beside the edge of a swamp near Robe, South Australia. The sole species, *A. leprosa*, was extensively described and illustrated by Southcott (1991) and placed in the trombidoid family Trombellidae. However, examination of the type specimens lodged in the South Australian Museum (SAM), reveals that the genus is misplaced and more closely resembles water mites of the family Hydryphantidae than mites of the family Trombellidae. A redescription of the genus is presented here, along with an examination of its systematic position within the Hydryphantidae.

Terminology mostly follows Cook (1974).

Family Hydryphantidae Piersig, 1896

Genus *Austrotrombella* Southcott, 1991

Austrotrombella Southcott, 1991: 207-208.

Type species: *Austrotrombella leprosa* Southcott, 1991, by monotypy.

Diagnosis

Differs from all other mites by the following combination of characters: pedipalpal tibia with distal seta; swimming hairs absent; lateral eyes in capsules; idiosoma with numerous large plates; median eye present and situated near posterior margin of prefrontalia; three pairs of acetabula in anterior group.

Remarks

Although regarded by Southcott (1991) as a member of the trombidoid family Trombellidae, *Austrotrombella* has more in common with the water mite family Hydryphantidae. In particular, the chelate morphology of the pedipalp, with a prominent dorso-distal tibial seta and a subdistally positioned tarsus, is virtually

diagnostic for the family (Cook 1974) and is completely unlike trombellids and other trombidoids which have the tarsus inserted subbasally on the tibia (e.g. Womersley 1934). In addition, the idiosoma lacks the dense vestiture of setae characteristic of most adult and nymphal trombidoids which is, instead, represented by longitudinal series of glandularia [termed 'cupulae' by Southcott (1991)].

The presence of lateral eyes in capsules and the lack of swimming hairs places the genus within the Thyasinae (Cook 1974) and the large dorsalia and ventralia suggest a strong similarity with the *Panisellus* group as defined by Bader (1985). This group contains *Panisellus* K. Viets (with *P. thiennemanni* (K. Viets) from northern Europe), *Placothyas* Lundblad (with *P. octopora* (K. Viets) from South Africa), *Octothyas* Lundblad (with *O. hewittae* Lundblad from South Africa), *Parathyas* Lundblad (with *P. thoracata* Piersig and *P. primitiva* Lundblad from Europe and North Africa) and *Thyasella* K. Viets (with *T. mandibularis* (Lundblad) from northern Europe). Therefore, *Austrotrombella* and its sole species, *A. leprosa*, is here transferred to the hydryphantid subfamily Thyasinae.

Austrotrombella leprosa differs from these other genera in a number of small but significant ways. It closely resembles *Panisellus* and *Placothyas* in the location of the postocularia within the prefrontalia and it differs from all members of the group by the possession of three pairs of acetabula in the anterior group (1-2 pairs in all others) and by the inclusion of the acetabula on to the genital flaps (published illustrations of all other genera appear to indicate that they are separate). It further differs from *Panisellus* by the presence of a median eye (absent in *Panisellus*) and from *Placothyas* by the posterior position of the median eye on the prefrontalia (situated near anterior margin in *Placothyas*) and the presence of 6-8 pairs of acetabula in the posterior group (2 pairs in *Placothyas*).

This species is only the second thyasine reported from Australia. The first, *Notopanisus vinulus* Harvey from Tasmania, differs by the lack of large dorsalia and ventralia (Harvey 1988).

* Western Australian Museum Francis Street Perth W. Aust. 6000.

Austrotrombella leprosa Southcott, 1991
(FIGS 1-8)

Austrotrombella leprosa Southcott, 1991: 208-211, Figs 1, 2, 3a-e, 4a-c.

Material Examined

Holotype: ♀, map reference (Penola 1: 250 000) 283411, Robe district, S.Aust. [37°12'S 139°47'E], in wet, alkaline, shellgrit-containing soil near swamp edge, under a stand of *Leptospermum lanigerum* (Aiton) Smith, 22.iii.1990, R. V. Southcott (SAM N1991112).

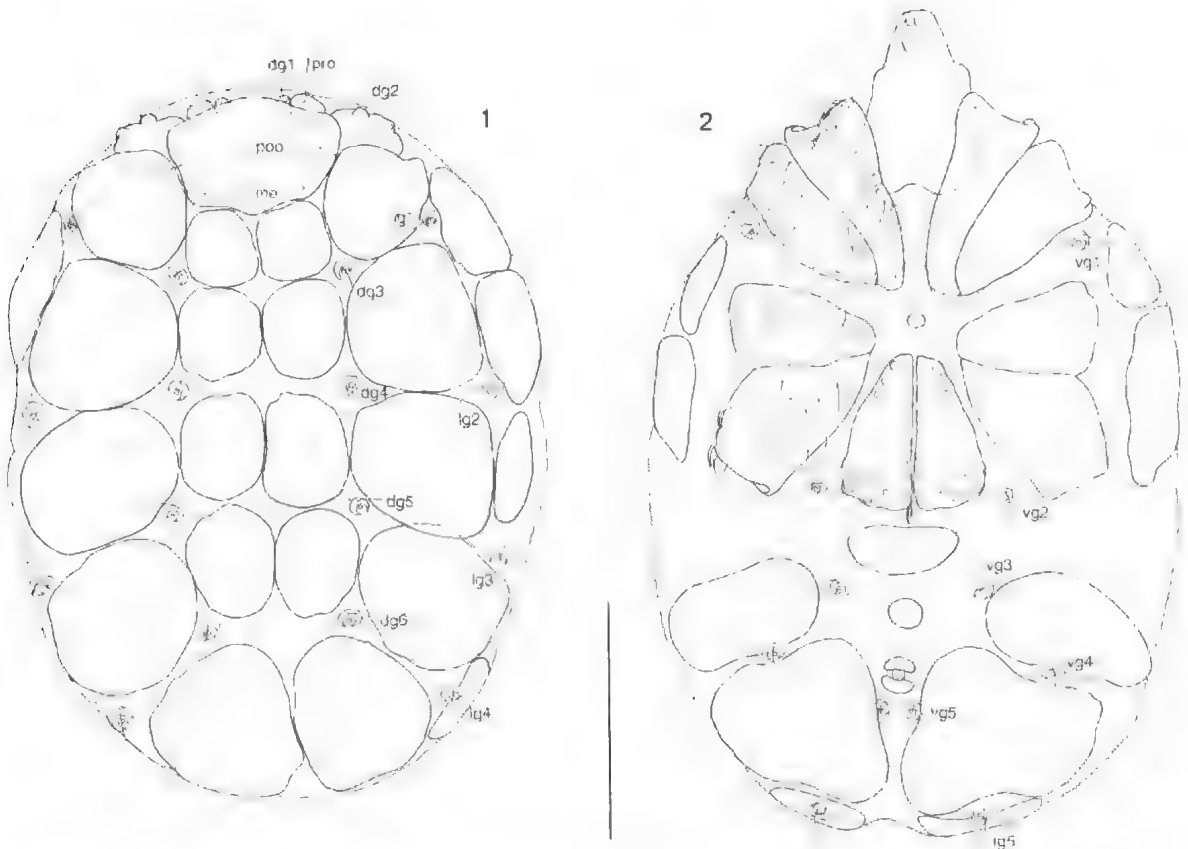
Paratypes: 1 ♀, 1 ♂, 1 deutonymph, same data as holotype (SAM N1991113-115).

Diagnosis

As for genus.

Description of adult

Integument slightly papillate. Lateral eyes on ocular capsules; anterior-lateral eye (not visible in Fig. 1) slightly larger than posterior-lateral eye; postocularia slightly posterior to median eye, situated near posterior margin of prefrontalia (Fig. 1). Idiosoma with numerous porose platelets arranged as follows: large prefrontalia; 1 pair of postfrontalia; 4 pairs of dorsocentralia, posterior pair larger than others; 4 pairs of dorsolateralia; 4 pairs of auxiliary platelets; 9 ventral platelets, 1 between coxal plates, 2 behind genital region, 2 pairs flanking anus, 1 pair situated posteriorly. Six pairs of dorsoglandularia, 5 pairs of lateroglandularia, 5 pairs of ventroglandularia (Figs 1, 2); sclerites associated with glandularia not forming full circle (Figs 1, 2); vg2 situated near postero-lateral margin of genital flaps and directed posterior-laterally;



Figs 1-2. *Austrotrombella leprosa* Southcott, holotype ♀. 1. Idiosoma, dorsal. 2. Idiosoma, ventral (setae omitted from one side). Abbreviations: dg1-6, dorsoglandularia; lg1-5, lateroglandularia; me, median eye; poo, postocularia; pro, preocularia; vg1-5, ventroglandularia. Scale bar = 500 µm.

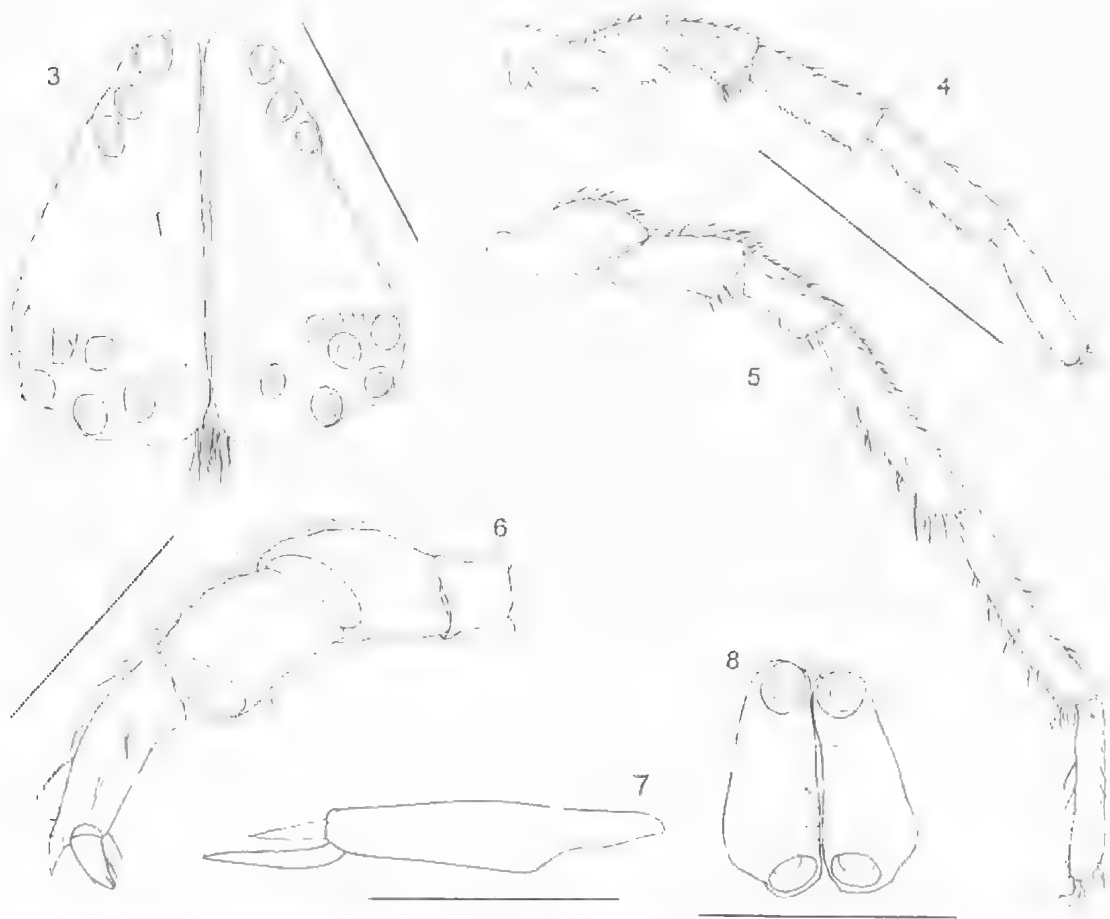
vg3 situated on level mid-way between genital flaps and anus; vg4 situated on same level as anus; vg5 situated much closer to anus than to posterior margin of body (Fig. 2). Genital region (Fig. 3): genital flaps with setae on mesal edge and scattered over posterior third; 9-11 pairs of acetabula, 3 pairs situated in anterior third, remainder (varying from 6-8 per side) situated on posterior third, all acetabula circular. Chelicera (Fig. 7) of normal proportions, cheliceral claw curved, with several teeth; cheliceral lamella about two-thirds as long as claw, serrate. Capitulum without long, downturned anterior extension. Pedipalp (Fig. 6): tibia with a thickened sub-medial seta on medial surface and with stout distal seta. Pedal coxae covered with long, thick setae (Fig. 2). Legs (Figs 4, 5) without swimming setae but most segments with numerous thick setae. Pedal claws completely smooth (Figs 4, 5). Anus surrounded by thick sclerotized ring (Fig. 2).

Dimensions (μm): holotype ♀: body length 1464,

width 1098; capitulum length 390; chelicera length 367; genital field length 333, width 314; pedipalp: trochanter 63, femur 139, patella 112, tibia 195, tarsus 51; leg I: trochanter 111, femur 250, patella 182, tibia 236, metatarsus 269, tarsus length 255, width 64; leg IV: trochanter 250, femur 276, patella 179, tibia 378, metatarsus 380, tarsus length 300, width 52.

Paratype ♀: body 1488/1104; capitulum length 435; chelicera length 385; genital field 381/346; pedipalp: not measurable; leg I: trochanter 109, femur 287, patella 173, tibia 262, metatarsus 302, tarsus 280/72; leg IV: trochanter 303, femur 321, patella 210, tibia 443, metatarsus 443, tarsus 350/58.

Paratype ♂: body 1408/1024; capitulum length 358; chelicera length 318; genital field 288/276; pedipalp: not measurable; leg I: trochanter 106, femur 251, patella 140, tibia 218, metatarsus 255, tarsus 266/59; leg IV: trochanter 230, femur 243, patella 163, tibia 336, metatarsus 362, tarsus 288/45.



Figs 3-8. *Austrotrombella leprosa* Southcott, 3-7, holotype ♀. 3. Genital field. 4. Right leg I. 5. Right leg IV. 6. Right pedipalp. 7. Left chelicera. 8. Provisional genital field, paratype deutonymph. Scale bars = 200 μm 3, 6, 7; 500 μm 4, 5; 100 μm 8.

Description of deutonymph

Much as in adult except as follows: genital flaps with 2 pairs of acetabula situated at anterior and posterior ends of flaps (Fig. 8).

Dimensions (μm): body length 582, width 406; genital field length 102, width 83.

Acknowledgments

I wish to thank David Hirst (South Australian Museum) for the opportunity to examine the type specimens of *Austrotrombella leprosa*.

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TRANSACTIONS OF THE

ROYAL SOCIETY

OF SOUTH AUSTRALIA

INCORPORATED

VOL. 120, PART 2

SEVENTEEN NEW SPECIES OF CASTIARINA (COLEOPTERA: BUPRESTIDAE)

*By S. BARKER**

Summary

Barker, S. (1996) Seventeen new species of Castiarina (Coleoptera: Buprestidae). Trans. R. Soc. S. Aust. 120(2), 41-59, 31 May, 1996.

Seventeen new species of Castiarina namely *C. adusta* sp. nov., *C. antarctica* sp. nov., *C. aura* sp. nov., *C. azurea* sp. nov., *C. charientessa* sp. nov., *C. daranj* sp. nov., *C. demarzi* sp. nov., *C. enigma* sp. nov., *C. ferruginea* sp. nov., *C. hemizostera* sp. nov., *C. jackhasenpuschi* sp. nov., *C. nonyma* sp. nov., *C. nullarborica* sp. nov., *C. paulhasenpuschi* sp. nov., *C. phaeopus* sp. nov., *C. subcincta* sp. nov., *C. ustulata* sp. nov., are described and three established species namely *C. cincta* (Blackburn), *C. femorata* (LaPorte & Gory), *C. octospilota* (LaPorte & Gory) are redescribed.

Key Words: Coleoptera, Buprestidae, new species, Castiarina.

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KEY WORDS: Coleoptera, Buprestidae, new species, *Castiarina*.

Introduction

The genus *Castiarina* (LaPorte & Gory) (Coleoptera: Buprestidae) is widely distributed in Australia and also occurs in New Guinea where its distribution and abundance are virtually unknown. The adults are often found on the flowers of native Myrtaceae species and the larvae which are root and stem feeders are largely unknown. Although twenty two new Australian species have been identified recently (Barker 1993, 1995) a further close examination of material collected over many years has revealed even more new species. Ten of these are associated with the *Castiarina parallela* (White) complex and all occur only in WA; two are associated with *C. octospilota* (LaPorte & Gory) and one each of these occurs only in NSW and WA. The specific status of a further species in this complex *C. femorata* (LaPorte & Gory) is restored from synonymy; this species also occurs in NSW. Five new species belonging to neither of these complexes are described from recently collected material.

The complex in WA has previously been misidentified as *C. parallela* (White) but in fact this species occurs only in the eastern states. All members of the group are elongate and have dark pronotum and elytral colours, most often rusty-brown but dark blue in two species, a yellow margin and a single row of yellow spots along the middle of each elytron with a maximum of four in each row and minimally one, when all of the spots are fused. All species in the complex have a dense layer of silver, flattened, feathery hair lining the entire ventral surface and encroaching on to the lateral surfaces of the pronotum. This distinguishes them from all other *Castiarina* which have thin, round hair on the ventral surface. Most of the new species

also have sculptured proctigera in both sexes and this feature is unique among *Castiarina* as all species outside this complex have rounded, unsculptured proctigera. The two species previously described from the complex in WA are *C. cricicolar* (LaPorte & Gory) and *C. octopunctata* (Barker 1995). Because this is the most difficult group of *Castiarina* to identify, I have included a key to the twelve known WA species.

C. octospilota (LaPorte & Gory) has a dark head with a yellow frontal spot, dark pronotum with yellow lateral margins and dark elytral markings with yellow spots. The ventral surface is yellow with blue sutural markings and blue legs. A species occurring on the eastern edge of the Darling Scarp, WA and on the coastal plains has long been misidentified as *C. octospilota*. It resembles *C. cincta* (Blackburn) which occurs inland but is easily distinguished by differences in colour, being blue and yellow with blue legs whilst *C. cincta* has some red markings on the elytra and red legs with red sutural markings. The aedeagi are different. There appear to be two species, *C. cincta* which is redescribed and a new species which is described.

None of the remaining five species is close to each other and all are distinctive. They have all been collected recently, one of them by use of a lure, a technique not used before for the capture of *Castiarina*.

Materials and Methods

Male genitalia were prepared and illustrated by the method described by Barker (1987). The holotype is illustrated in all new species except one in which the allotype is illustrated. Measurements given are mean total body length and width with standard error, except where there are insufficient specimens to make the last calculation. Codens used in the text for museum and private collections following the four letter system of

* Department of Zoology, University of Adelaide S. Aust. 5005.

Watt (1979) and Arnett *et al.* (1993) are: ANIC: Australian National Insect Collection, Canberra; BMNH: British Museum (Natural History), London; MNHN: Museum Nationale Histoire Naturelle, Paris; NMVA: National Museum of Victoria, Melbourne; SAMA: South Australian Museum, Adelaide; WAMA: Western Australian Museum, Perth; HDWA Mr H. Demarz, Guilderton; JHQA: Mr J Hasenpusch, Innisfail; MHSA: Mr T. M. S. Hanlon, Sydney. MPWA: Mr M. Powell, Melville.

Castiarina femorata (LaPorte & Gory) 1838
(FIGS 1B, 2B)

Stigmodera femorata LaPorte & Gory 1838: 37, Pl 8, Fig. 42.

Stigmodera (*Castiarina*) *octospilota* var. *roseipes* Deuquet, 1956 (new syn.).

Holotype: Sex unknown, *S. femorata* LaPorte & Gory, Aust. MNHN (not seen)

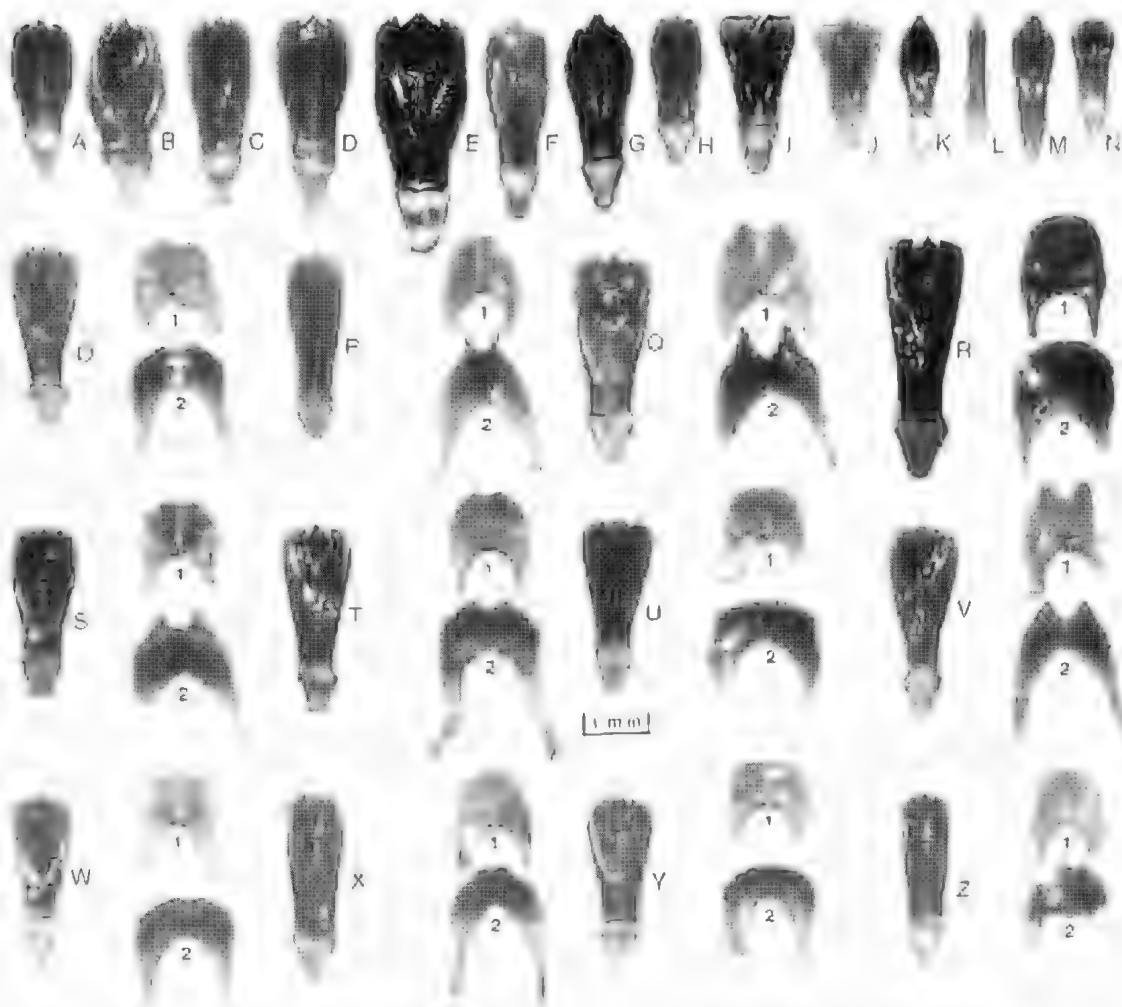


Fig. 1. Photomicrographs of aedeagi and male and female proctigera of the following *Castiarina* species. A. *Castiarina daranyi* sp. nov. B. *C. femorata* (L & G). C. *C. cincta* (Blackburn). D. *C. subcincta* sp. nov. E. *C. octospilota* (L & G). F. *C. paulhasenpuschi* sp. nov. G. *C. bucolica* (Kerremans). H. *C. demarzi* sp. nov. I. *C. placida* (Thomson). J. *C. nullarborica* sp. nov. K. *C. cydista* (Rainbow). L. *C. jackhasenpuschi* sp. nov. M. *C. aglaia* Barker. N. *C. hemizostera* sp. nov. O. *C. antarctica* sp. nov. 1, proctiger male, 2, proctiger female. P. *C. octopunctata* Barker. 1, proctiger male, 2, proctiger female. Q. *C. ferruginea* sp. nov. 1, proctiger male, 2, proctiger female. R. *C. adusta* sp. nov. 1, proctiger male, 2, proctiger female. S. *C. aura* sp. nov. 1, proctiger male, 2, proctiger female. T. *C. charientessa* sp. nov. 1, proctiger male, 2, proctiger female. U. *C. azurea* sp. nov. 1, proctiger male, 2, proctiger female. V. *C. ustulata* sp. nov. 1, proctiger male, 2, proctiger female. W. *C. phaeopus* sp. nov. 1, proctiger male, 2, proctiger female. X. *C. nonyma* sp. nov. 1, proctiger male, 2, proctiger female. Y. *C. enigma* sp. nov. 1, proctiger male, 2, proctiger female. Z. *C. crucicolor* (L & G). 1, proctiger male, 2, proctiger female.

Colour

Head dark blue with green and purple reflections, elongate yellow frontal spot, muzzle blue. Antennae blue. Pronotum dark blue with yellow lateral margins width increasing basally. Scutellum dark blue. Elytra yellow with following dark blue markings: narrow basal margin, elongate sinuous vitta on each side meeting basal margin over humeral callus, meeting post-medial fascia at margin enclosing spot on margin, apical mark enclosing elongate yellow mark between it and post-medial fascia, small yellow apical spot on each side of suture, marks all connected along suture. Ventral surface yellow with testaceous-red sutures and testaceous-red edges to abdominal segments, except S_7 . Legs: coxae and trochanters testaceous-red and dark blue; femora mainly testaceous-red, apically dark blue; tibiae a dark blue with ventral testaceous-red mark near ventral apex; tarsi blue. Hairs silver.

Shape and sculpture

Head shallowly punctured, median sulcus narrow, muzzle short. Antennomeres 1-3 obconic, 4 half-toothed, 5-II toothed. Pronotum shallowly punctured, apical margin straight, basal margin barely bisinuate,

median basal fovea projecting almost to middle as glabrous line; laterally parallel-sided at base, rounded to apex. Scutellum scutiform, unpunctured. Elytra punctate-striate, intervals convex, more so apically than basally, lightly punctured; laterally angled outwards from base, rounded at humeral callus, rounded post-medially and narrowed to trispinose apex, marginal spine small, interval to small median spine straight, margin rounded and indented to small sutural spine; apices slightly divergent. Ventral surface shallowly punctured, edges of abdominal segments glabrous, elsewhere with sparse long hair, S_7 : male rounded; female round, indented medially.

Size

Males, $12.4 \pm 0.35 \times 4.9 \pm 0.14$ mm (20). Females, $13.4 \pm 0.22 \times 5.5 \pm 0.09$ mm (5).

Aedeagus (Fig. 1B)

Parameres angled outwards from basal piece, rounded premedially then narrowed, rounded apically. Penis sharp, sides acutely angled away. Hypophysis of basal piece medium width, apices rounded.

Distribution

NSW: Armidale district, ventral coastal.

Remarks

This species was synonymised with *C. octospilota* by Saunders (1868) who was followed by all subsequent authors. Deuquet (1956) gave the varietal name *roseipes* to a specimen he identified as *S. octospilota*. A single male specimen in the South Australian Museum identified as *Stig.8-spilota* L. & G. var. *roseipes* Deuq. in Deuquet's handwriting, is clearly a separate species from *C. octospilota*. The holotypes of *C. octospilota* and *C. femorata* are both lodged in the MNHN but cannot be identified because their labels, along with those of all other LaPorte & Gory type labels, have been removed. Deuquet's description of the red femora and red vermiculation on the ventral surface of his *S. octospilota* var. *roseipes* concurs with the original description of *S. femorata*. The figure of *S. femorata* (LaPorte & Gory 1838, Pl. 8, Fig. 42) also conforms in general, except that the illustration shows the base of the head to be yellow instead of the yellow frontal spot in the Deuquet specimen. I assume that this is artistic licence on the part of the illustrator because none of the species in this species group has a head with a yellow base. In the figure the pre-medial fascia is complete. A similar pattern is present in only two of the fourteen specimens examined. All other specimens have the pre-medial fascia incomplete; thus two spots on each side of the suture coalesce to form a sinuous yellow vitta. *S. octospilota* var. *roseipes* Deuquet is undoubtedly a synonym of *C. femorata* (L. & G.).

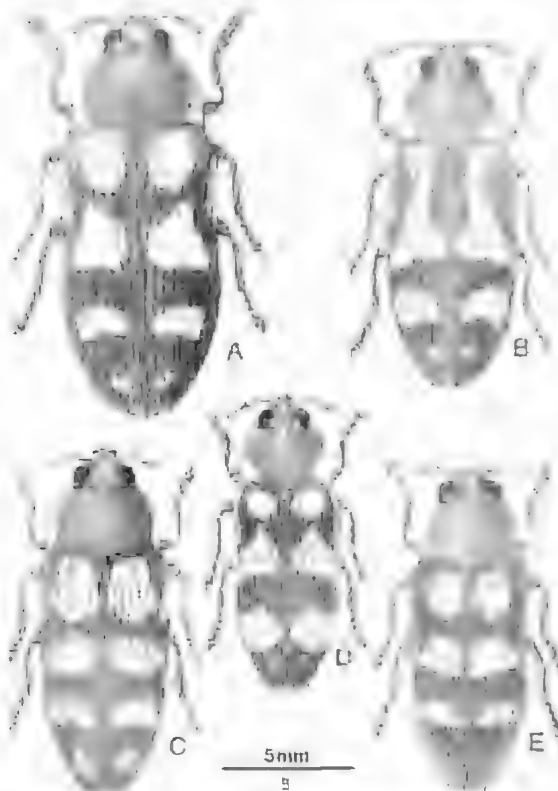


Fig. 2. Habitus illustrations of the following *Castiarina* species. A. *Castiarina octospilota* (L. & G.), B. *C. femorata* (L. & G.), C. *C. subeincta* sp. nov. holotype. D. *C. darwin* sp. nov. holotype. E. *C. cincta* (Blackburn).

Castiarina octospilota (LaPorte & Gory)
(FIGS 1E, 2A)

Stigmodera octospilota LaPorte & Gory 1838: 28, Figs 29, Pl. 6.

Holotype: Sex unknown, Australia, MNHN (not seen)

Colour

Head: muzzle blue; base dull green-purple; yellow frontal mark. Antennae blue. Pronotum: medially dull green-purple; laterally yellow, base wider than apex. Scutellum black with dark blue reflections. Elytra yellow with following dark blue markings: narrow basal margin, small and narrow pre-medial fascia absent in many specimens, connected to long oblique vitta from lower end reaching lateral margin, enclosing very large basal yellow spot and smaller one on margin; broad post-medial fascia reaching lateral margin, slightly angled posteriorly, enclosing large yellow mark between it and first fascia; mark covering whole apex, enclosing small yellow mark between it and second fascia. Ventral surface yellow with blue sutures. Legs blue. Hairs silver

Shape and sculpture

Head closely punctured, median sulcus small, muzzle short. Antennomeres 1-3 obconic, 4 half-toothed, 5-11 toothed. Pronotum closely punctured, minute basal fovea extending forwards to middle as glabrous line, basal notches represented by glabrous areas, more marginal than medial; apical margin straight; basal margin bisinuate; laterally rounded out from base, widest pre-medially, rounded and narrowed to apex. Scutellum scutiform, glabrous, excavate at basal edge. Elytra punctate-striate, intervals convex and punctured, less so medially than elsewhere; laterally angled out from base, rounded at humeral callus, concave, rounded post-medially and narrowed to trispinose apex; small marginal and medial spines, margin between straight, widely separated, small sutural spine, close to medial spine, apices divergent. Ventral surface with shallow punctures, edges of abdominal segments glabrous, elsewhere moderately hairy, hairs medium length. S_7 truncate and indented medially in both sexes.

Size

Males, $12.5 \pm 0.28 \times 5.1 \pm 0.20$ mm (33). Females, $13.6 \pm 0.23 \times 5.6 \pm 0.11$ mm (40).

Aedeagus (Fig. 1E)

Parameres angled outwards from basal piece, rounded pre-medially, parallel-sided, rounded at apex. Penis sharp, sides obtusely angled away. Apophysis of basal piece medium width, apically rounded.

Distribution

NSW: Blue Mts, Sydney, central to north coastal. Qld: Southern and central coastal. Blackdown Tableland, Shrove Is.

Castiarina cincta (Blackburn) 1890
(FIGS 1C, 2E)

Stigmodera cincta Blackburn 1890: 13, 157 (replacement name for *S. rubrocincta* Kerremans 1890: 46, primary homonym *S. rubrocincta* Gehin 1855).

Holotype: ♀, *S. rubrocincta* Kerremans, Boucard Australia. BMNH.

Colour

Head: muzzle blue-green; base purple-green; large yellow frontal mark. Antennae blue-green. Pronotum laterally yellow, medially purple-green. Scutellum blue. Elytra yellow with the following dark blue markings: basal margin; pre-medial fascia not reaching margin with ends projecting anteriorly to basal margin as vitta enclosing large yellow basal spot, elongate yellow mark on margin at humeral callus, narrow red apical margin; post-medial fascia not reaching margin, enclosing yellow band between it and first fascia; pre-apical mark in shape of short fascia enclosing elongate yellow band between it and second fascia, all marks connected along suture. Lateral red margin on the two intervals from humeral callus, broader at pre-apex and apex. Ventral surface yellow; sternum lateral blue-green sutural marks, red medially and along edges of abdominal segments. Legs: femora blue-green apically, red medially, tibiae and tarsomeres blue-green. Hairs silver.

Shape and sculpture

Head with shallow punctures, flat, muzzle short. Antennomeres 1-3 obconic, 4 half-toothed, 5-11 toothed. Pronotum with shallow punctures, basal fovea represented by shallow depression, very small basal notches more marginal than medial; apical margin straight, basal margin almost straight. Scutellum scutiform, without punctures, excavate along basal edge. Elytra punctate-striate, intervals flat medially, convex apically and laterally, punctured, less so medially; laterally angled out slightly from base, rounded at humeral callus, concave, rounded post-medially and narrowed to trispinose apex; marginal spine small and sharp, median spine larger and blunt, sutural spine small and sharp, margin rounded between spines. Ventral surface with shallow punctures, sparse short hair, S_7 truncate both sexes.

Size

Males, $11.3 \pm 0.22 \times 4.3 \pm 0.10$ mm (24). Females, $12.2 \pm 0.34 \times 4.7 \pm 0.15$ mm (20).

Aedeagus (Fig. 1C)

Parameres angled outwards from basal piece, rounded pre-medially then angled outwards, rounded apically. Penis sharp, sides acutely angled away. Hypophysis of basal piece narrow, apically rounded.

Distribution

Occurs in inland south-western WA.

Castiarina daranj sp. nov.
(FIGS 1A, 2D)

Holotype: ♂, 4 km NE Rocky Glen, NSW, 3.xi.1981, S. Barker, SAMA I 21 300.

Allotype: ♀, same data as holotype, SAMA I 21 301.

Paratypes: NSW: 1 ♀, 43 km S Narrabri, 27.x.1975, S. Barker, SAMA; 14 ♂♂, 8 ♀♀, Binnaway, 2.xi.1981, S. Barker, SAMA; 1 ♀, 6 km SW Rocky Glen, 3.xi.1981, S. Barker, SAMA; 2 ♂♂, 2 ♀♀, 4 km SW Rocky Glen, 3.xi.1981, S. Barker, SAMA; 1 ♀, 3 km SW Rocky Glen, 3.xi.1981, S. Barker, SAMA; 1 ♂, 1 ♀, 2 km SW Rocky Glen, 3.xi.1981, S. Barker, SAMA; 5 ♂♂, 4 ♀♀, same data as holotype, SAMA; 2 ♂♂, 2 ♀♀, Garrawilla T.O. 6 km NE Rocky Glen, 3.xi.1981, S. Barker, SAMA; 2 ♀♀, Garrawilla T.O., 8.xi.1981, R. Anderson, SAMA; 1 ♀, Garrawilla T.O., 12.xi.1981, S. Barker, SAMA; 1 ♂, 6 km NE Coonabarrabran, 6.xi.1983, A. M. Sundholm, MHSA; 3 ♂♂, 1 ♀, 40 km E Coonabarrabran, 9.xi.1990, T. M. S. Hanlon, MHSA; 1 ♂, 60 km N Coonabarrabran, 9.xi.1990, T. M. S. Hanlon, MHSA; 2 ♂♂, 2 ♀♀, 40 km E Coonabarrabran, 8.xi.1991, T. M. S. Hanlon, MHSA; 1 ♂, Round Hill, 21.xi.1991, T. M. S. Hanlon, MHSA; 1 ♂, 30 km E Parkes, 29.xi.1993, T. M. S. Hanlon, MHSA.

Colour

Head black with green reflections, muzzle blue, large orange-yellow frontal spot. Antennae blue. Pronotum medially dark blue, laterally orange-yellow increasing in width basally. Scutellum dark blue. Elytra orange-yellow with the following black markings with blue reflections: narrow basal margin; sinuous vitta from basal margin over humeral callus meeting margin and sutural mark enclosing yellow-orange elongate mark on margin and basal spot; broad post-medial fascia reaching margin enclosing large orange-yellow mark between it and first mark; mark covering apex meeting post-medial fascia on margin and enclosing a large orange-yellow mark; small orange-yellow apical spot

on each side. Ventral surface orange-yellow with blue marks along sutures and along edges of abdominal segments. Legs: femora and tibiae blue; tarsi bright blue. Hairs silver.

Shape and sculpture

Head shallowly punctured, median sulcus shallow, muzzle short. Antennomeres 1-3 obconic, 4 half-toothed, 5-11 toothed. Pronotum shallowly punctured, narrow basal fovea extending forwards to middle as glabrous line; apical margin projecting medially, basal margin barely bisinuate; laterally parallel-sided at base, rounded to apex. Scutellum scutiform, glabrous, excavate. Elytra punctate-striate, intervals convex, lightly wrinkled and punctured; laterally angled out from base, rounded at humeral callus, concave, rounded post-medially and narrowed to trispinose apex; spines small, margin straight between marginal and median spine, rounded between median and sutural spines, apices divergent. Ventral surface with shallow punctures, edges of abdominal segments glabrous, elsewhere moderately hairy, sparse medium length hair. S_7 : male truncate, slightly indented medially; female truncate, deeply indented medially, margin overhanging apex which is covered with bristles.

Size

Males, $10.4 \pm 0.15 \times 4.0 \pm 0.06$ mm (34). Females, $11.1 \pm 0.20 \times 4.4 \pm 0.09$ mm (26).

Aedeagus (Fig. 1A)

Short. Parameres angled outwards from basal piece, rounded pre-medially, parallel-sided, apically rounded. Penis sharp, sides acutely angled away. Hypophysis of basal piece medium width, apically rounded.

Remarks

The basal colour of this species fades rapidly in death from orange-yellow to pale yellow. Both *C. octospilota* and *C. femorata* have a yellow basal colour in life. Also it is smaller than the other two species and the male genitalia are smaller and a different shape (Figs 1A, 1B, 1E).

Etymology

Name derived from Arabic *daranj*, orange.

Castiarina subcincta sp. nov.
(Figs 1D, 2C)

Holotype: ♂, Bold Park, City Beach, WA, 3.xi.1976, R. P. McMillan, SAMA I 21 302.

Allotype: ♀, City Beach, WA, 3.xii.1955, J. A. L. Watson, SAMA I 21 303.

Paratypes: WA: 1 ♀, Cannington, 12.xii.1954, S. Barker, SAMA; 3 ♂♂, City Beach, 24.x.1954, S. Barker, SAMA; 12 ♂♂, 3 ♀♀, City Beach, 26.xi.-25.xii.1955, J. A. L. Watson, SAMA; 1 ♀, 9.5 km SW Jarrahdale, 11.xi.1956, S. Barker, SAMA; 1 ♂, City Beach, 6.xi.1957, S. Barker, SAMA; 1 ♂, City Beach, 2.x.1964, S. Barker, SAMA; 3 ♂♂, Wembly, 3.x.1970, S. Barker, SAMA; 4 ♂♂, 1 ♀, same data as holotype, SAMA; 2 ♂♂, 1 ♀, Glen Eagles, 7.i.1983, S. Barker & K. T. Richards, SAMA; 2 ♂♂, 3 ♀♀, Walyunga N.P., 4.xi.1984, T. M. S. Hanlon, MHSA; 5 ♂♂, 1 ♀, Wembly, 4.xi.1985, T. M. S. Hanlon, MHSA; 1 ♂, Swanbourne, 23.x.1991, T. M. S. Hanlon, MHSA; 6 ♂♂, 1 ♀, Swan R., H. W. Brown, SAMA.

Colour

Head basally dark blue, with green and purple reflections, muzzle blue, large yellow frontal spot. Antennae dark blue. Pronotum medially dark blue with green and purple reflections, laterally yellow. Scutellum dark blue. Elytra yellow with following black markings with blue reflections: narrow basal margin; sinuous vitta from basal margin over humeral callus meeting narrow pre-medial fascia close to margin enclosing a yellow spot on margin and large yellow basal spot; broad post-medial fascia reaching margin enclosing yellow spot between it and pre-medial fascia, mark covering apex enclosing elongate yellow mark between it and post-medial fascia and variable apical yellow spot, all marks connected along suture and along margin except at humeral callus; outer margin of apical spot variably red. Ventral surface yellow, sutures blue and lateral blue spots on S_3 , S_5 , S_6 . Legs blue. Hairs silver.

Shape and sculpture

Head shallowly punctured, median sulcus small and shallow, muzzle short. Antennomeres 1-3 obovate, 4 half-toothed, 5-II toothed. Pronotum shallowly punctured, narrow basal fovea extending forwards to middle as glabrous line, basal notches represented by glabrous area on each side closer to margin than middle; apical margin projecting medially, basal margin almost straight; laterally parallel-sided at base, rounded from base to apex. Scutellum scutiform, glabrous, flat. Elytra punctate-striate, intervals convex, wrinkled; laterally angled out from base, rounded at humeral callus, concave, rounded post-medially, narrowed to trispinose apex; small marginal spine, larger medial spine, smaller sutural spine, margin rounded between spines, apices diverging. Ventral surface with shallow punctures, edges of abdominal segments glabrous, elsewhere sparse medium length hairs. S_7 : truncate both sexes.

Size

Males, $12.8 \pm 0.13 \times 4.9 \pm 0.06$ mm (41). Females, $13.5 \pm 0.22 \times 5.2 \pm 0.09$ mm (24).

Aedeagus (Fig. 1D)

Parameres angled outwards from basal piece, rounded pre-medially, parallel-sided, rounded apically. Penis sharp, sides acutely angled away. Hypophysis of basal piece narrow, apically rounded.

Remarks

This species, previously confused with *C. octospilota*, forms a species pair with *C. cincta* (Blackburn). It occurs on the coastal plain of WA and on the western edge of the Darling Scarp whereas *C. cincta* occurs in the more arid inland areas of the south-west. It differs from that species having only very small red markings on the elytra and not on the legs or abdominal segments. *C. cincta* has red markings on the elytra, red femora and red sutures on the ventral surface. Also the elytral spines are more obvious in *C. subcincta* than in *C. cincta* and the male genitalia are a different shape (Figs 1C, 1D).

Etymology

The name is derived from *L. sub*, under *L. cinctum*, girdle.

Castiarina adusta sp. nov. (Figs 1R, 1R1, 1R2, 3I)

Holotype: ♂, 5 km W Mt Dale, WA, 13.x.1980, S. Barker, SAMA I 21 304.

Allotype: ♀, Lake Grace, WA, 19.x.1970, K. & E. Carnaby, ANIC

Paratypes: WA: 5 ♂♂, 3 ♀♀, same data as allotype, ANIC, 1 ♀, 80 km E Hyden, 29.x.1984, M. Powell, MPWA; 1 ♂, 1 km WNW Bonnie Rock, 20.ix.1990, S. Barker, SAMA

Colour

Head, antennae and pronotum bronze. Scutellum dark blue. Elytra yellow with the following brown markings: marks coalesced leaving a continuous yellow margin from base to near apex, a row of four elongate spots down each elytron, the first two variably connected. Ventral surface and legs bronze. Hairs silver.

Shape and sculpture

Head shallowly punctured, median sulcus shallow, sides variably glabrous basally, muzzle short. Antennae

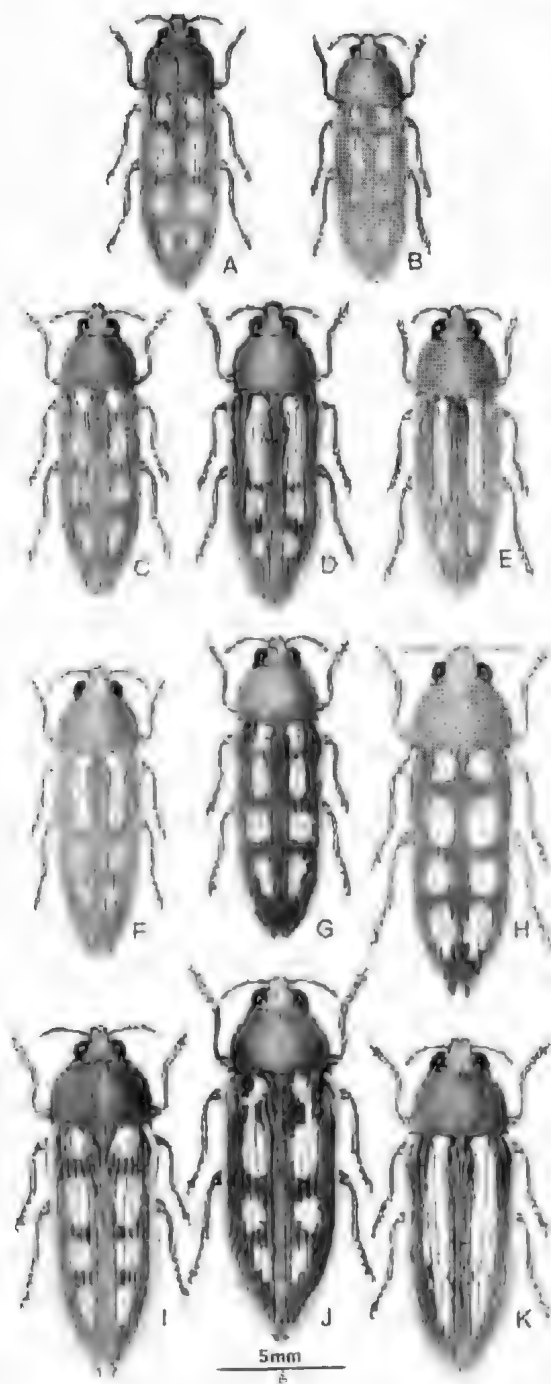


Fig. 3. Habitus illustrations of the following *Castiarina* species. A. *Castiarina nonyma* sp. nov. holotype. B. *C. rrocolor* (L. & G). C. *C. enigma* sp. nov. holotype. D. *C. antarctica* sp. nov. holotype. E. *C. phaeopus* sp. nov. holotype. F. *C. ustulata* sp. nov. holotype. G. *C. azurea* sp. nov. holotype. H. *C. ferruginea* sp. nov. holotype. I. *C. aura* sp. nov. holotype. J. *C. adusta* sp. nov. holotype. K. *C. charientessa* sp. nov. holotype.

meres 1-3 obconic, 4-11 toothed. Pronotum shallowly punctured medially, larger and deeper punctures laterally, narrow basal fovea extending anteriorly to middle as glabrous line, basal notches represented by glabrous area on each side closer to margin than middle; apical margin projecting medially, basal margin barely bisinuate; laterally parallel-sided at base, rounded and narrowed to apex, laterally hairy. Scutellum scutiform, punctured, flat. Elytra punctate-striate, intervals convex, wrinkled and punctured; laterally angled out from base, rounded at humeral callus, concave, rounded post-medially and narrowed to bispinose apex; spines small and blunt, margin variably rounded and indented or straight between spines, apices hardly diverging. Ventral surface with shallow punctures, edges of abdominal segments glabrous, elsewhere hairy, hairs flattened and feathery. Legs: femora hairy with flattened hair. S₇: males truncate; females rounded.

Size

Males, $14.5 \pm 0.12 \times 5.0 \pm 0.06$ mm (7), Females, $15.9 \pm 0.45 \times 5.4 \pm 0.12$ mm (5).

Aedeagus (Fig. 1 R1)

Parameres angled outwards from basal piece, rounded pre-apically then parallel-sided, rounded apically. Penis sharp, sides acutely angled away. Hypophysis of basal piece medium width, rounded apically. Proctiger, medial apical edge shallowly concave, rounded laterally (Fig. 1 R1).

Female terminalia (Fig. 1 R2)

Proctiger with apical edge flattened, rounded laterally.

Remarks

C. adusta sp. nov. is the largest member of this group in WA. It can be separated from *C. ferruginea* sp. nov., the next largest brownish species, by its size, the conformation of the elytral markings - there are four spots in *C. ferruginea* and three in *C. adusta*, its relatively unsculptured proctiger in both male and female, whereas both sexes of *C. ferruginea* have bilobed proctigers and in females they are spined. The aedeagus in *C. ferruginea* is broader at the apex than that of *C. adusta* (Figs 1Q, 1R).

Etymology

The name is derived from *L. adustus*, brown.

Castiarina azurea sp. nov. (FIGS 1U, 1 U1, 1 U2, 3G)

Holotype: ♂, 2 km E Tallering Station, Pindar, WA, 22.ix.1989, S. Barker, SAMA 1 21 305.

Allotype: ♀, same data as holotype, SAMA I 21 306.

Paratypes: WA: 1♂, Goomalling, 13.ix.1953, R. P. McMillan, WAMA; 1♂, 2♀♀, Moorine Rock, 16.x.1953, F. H. Uther Baker, SAMA; 1♀, Wialki, 9.ix.1957, S. Barker, SAMA; 1♂, Toohbin, 18.x.1958, F. H. Uther Baker, SAMA; 2♂♂, Burtacoppin, 16.x.1963, F. H. Uther Baker, WAMA; 3♂♂, 2♀♀, 78 km NE Wubin, 17.ix.1970, S. Barker, SAMA; 1♀, 98 km NE Wubin, 17.ix.1970, S. Barker, SAMA; 2♂♂, 1♀, 55 km S Payne's Find, 18.ix.1970, SAMA; 1♂, 1♀, 57 km S Payne's Find, 18.ix.1970, S. Barker, SAMA; 2♀♀, 10 km E Elachburting Rock, Wialki, 20.ix.1970, S. Barker, SAMA; 5♂♂, 2♀, Wialki, 21.ix.1970, S. Barker, SAMA; 2♂♂, 2♀♀, Wulgoolan, 9.ix.1971, F. H. Uther Baker, SAMA; 1♂, Tallering Station, Pindar, 3.ix.1976, R. P. McMillan, SAMA, 5♂♂, 3♀♀, 18.9 km WSW Cnoolgardie, 18.ix.1976, R. J. Chinnock, SAMA; 1♂, 50 km N Kalbarri, 20.viii.1978, M. Powell, WAMA; 1♂, Balline Station, 24/25.vii.1979, A. M. & M. J. Douglas, WAMA; 1♂, 2♀♀, Muckinbudin, 10.x.1979, R. P. McMillan, WAMA; ♂, 16 km E Mt Magnet, 20.ix.1980, S. Barker & D. J. Williams, SAMA; 1♂, 19 km N Carnarvon, 22.ix.1980, S. Barker & D. J. Williams, SAMA; 1♂, 2♀♀, 89 km N Carnarvon, 22.ix.1980, S. Barker & D. J. Williams, SAMA; 1♂, 2♀♀, 44 km E Kalbarri, 26.ix.1980, S. Barker & D. J. Williams, SAMA; 3♂♂, 46 km E Kalbarri, 26.ix.1980, S. Barker & D. J. Williams, SAMA; 2♂♂, 1♀, S Ram paddock, Tallering Station, Pindar, 27.ix.1980, S. Barker & D. J. Williams, SAMA; 2♂♂, 1♀, 17 km W Mullewa, 29.ix.1980, S. Barker & D. J. Williams, SAMA; 2♀♀, Mt Walker, 23.x.1980, R. P. McMillan, WAMA; 1♀, Gabbie, 29.x.1981, R. P. McMillan, WAMA; 2♀♀, Southern Cross, x.1981, R. P. McMillan, WAMA; 1♂, 3♀♀, 2 km N Ivanston, 23.ix.1982, B. Hanich & T. F. Houston, WAMA; 1♀, 64 km NE Esperance, 18.x.1982, S. Barker, SAMA; 1♂, Bullfinch, 2.x.1983, B. Jones, MPWA; 1♀, 35 km W Salmon Gums, 8.x.1983, G. Browning & G. Mutze, SAMA; 3♂♂, 1♀, Southern Cross, 8.x.1983, R. P. McMillan, WAMA; 6♂♂, 4♀♀, Esperance to Norseman Hwy, 35 km W T.O. to Peake Charles, 9.x.1983, G. Browning & G. Mutze, SAMA; 2♀♀, 35 km E Merredin, 24.x.1983, G. Browning, SAMA; 1♂, 2♀♀, 50 km E Merredin, 24.x.1983, SAMA; 1♂, Ubertin Rock, 15.ix.1984, R. P. McMillan, WAMA; 1♂, 136 km NE Payne's Find, 30.ix.1984, M. Powell, MPWA; 1♂, 3 km W Dowerin, 22.x.1984, R. P. McMillan, WAMA; 1♂, Eneabba, 4.x.1985, R. P. McMillan, WAMA; 1♂, N Tarin Rock reserve, 15/16.x.1985, T. F. Houston, WAMA; 1♂, 75 km E Hyden, 24/27.x.1985, T. F. Houston, WAMA; 6♂♂, W of Coorow, 2.x.1986, A. G. Wells, WAMA; 1♂, 16 km NE Merredin, 9.x.1986, R. P. McMillan, WAMA; 2♂♂, Eneabba, x.1986, R.

P. McMillan, WAMA; 1♂, Bindoo Hill reserve, 12.ix.1987, T. F. Houston, WAMA; 2♂♂, 1♀, 7 km SSW Jingemarra Station, 24/26.viii.1988, R. P. McMillan & T. F. Houston, WAMA; 1♀, Shark Bay, 29.viii.1988, A. Hay, MHSA; 1♂, 110 km N Carnarvon, 18.ix.1989, S. Barker, SAMA; 2♂♂, 1♀, Pindar paddock, Tallering Station, Pindar, 21.ix.1989, S. Barker, SAMA; 7♂♂, same data as holotype, SAMA; 1♂, 1♀, 3 km N Tallering Station, Pindar, 22.ix.1989, S. Barker, SAMA; 2♂♂, 6 km N Tallering Station, Pindar, 22.ix.1989, S. Barker, SAMA; 5♂♂, 19 km N Tallering Station, Pindar, 22.ix.1989, S. Barker, SAMA; 1♂, gravel bay, Bonnie Rock, 20.ix.1990, S. Barker, SAMA; 2♂♂, Merredin, 21.x.1991, T. M. S. Hanlon, MHSA; 8♂♂, Ghooli, 21.x.1991, T. M. S. Hanlon, MHSA; 2♂♂, 3 km S Yellodine, 21.x.1991, T. M. S. Hanlon, MHSA; 5♂♂, N7T, 32 km E Southern Cross, 21.x.1991, T. M. S. Hanlon, MHSA; 1♂, Queen Victoria Springs, 21/22.xi.1992, D. Knowles, MHSA; 2♂♂, 1♀, Northam, SAMA; 2♂♂, Ankertell, H. W. Brown, SAMA.

Colour

Head dark blue with purple reflections. Antennae bronze. Pronotum dark blue with purple reflections. Scutellum purple. Elytra with yellow background colour and dark blue elytral markings, coalesced forming four yellow spots on each elytron, basal more or less rounded, pre-medial elongate, post-medial rounded, pre-apical elongate, basal and pre-medial coalesced in about half specimens examined forming an elongate mark, post-medial and pre-apical coalesced in only one specimen examined, yellow margin from base to near apex. Ventral surface bronze with coppery-purple reflections. Hairs silver.

Shape and sculpture

Head closely punctured, median suture present, muzzle short. Antennomeres 1-3 obconic, 4-11 toothed. Pronotum closely punctured, narrow basal fovea extending forwards to middle as glabrous line, basal notches represented by glabrous area on each side closer to margin than middle; apical margin projecting medially, basal margin almost straight; laterally angled inwards from base for short distance then angled outwards and rounded to widest part post-medially, rounded and narrowed to apex. Scutellum scutiform, punctured, flat. Elytra punctate-striate, intervals convex, wrinkled and punctured, more heavily laterally than medially; laterally angled out from base, rounded at humeral callus, concave, rounded post-medially, narrowed to bispinose apex; marginal spine small and sharp, sutural spine minute, margin indented and rounded between spines, apices hardly diverging. Ventral surface with shallow punctures, edges of abdominal segments glabrous, elsewhere hairy, hairs medium length, flattened and leathery. ♂: truncate in males, rounded in females.

Size

Males, $10.1 \pm 0.15 \times 3.2 \pm 0.05$ mm (110). Females, $10.7 \pm 0.24 \times 3.4 \pm 0.08$ mm (56).

Aedeagus (Fig. 1U)

Parameres angled outwards from basal piece, rounded at apex. Penis sharp, sides obtusely angled away. Apophysis of basal piece medium width, apex rounded. Proctiger faintly bilobed, lobes rounded (Fig. 1U1).

Female terminalia (Fig. 1U2)

Proctiger faintly bilobed, lobes faintly rounded.

Remarks

C. azurea can be distinguished from all other members of the *C. parallela* species group except *C. octopunctata* by the dark blue colour of the elytra. *C. octopunctata* has round yellow elytral markings whereas they are elongate in *C. azurea*. In *C. azurea* the aedeagus is short and broad and in *C. octopunctata* it is elongate (Figs 1P, 1U). The proctigers in both sexes of *C. octopunctata* have pointed lobes whereas in both sexes of *C. azurea* the proctiger lobes are small and rounded (Figs 1P1, 1P2, 1U1, 1U2). There appears to be a cline in size within *C. azurea*. Specimens from north of Carnarvon and from the NE wheatbelt areas of WA are larger than those from further east and south. A minority of specimens has the first two yellow marks on the elytra fused to form an elongate basal mark.

Etymology

The species name is derived from F *azur*, blue.

***Castiarina charientessa* sp. nov.**
(FIGS 1T, 1T1, 1T2, 3K)

Holotype: ♂, 10 km S Dongara, WA, 4.ix.1995, S. Barker, SAMA 1 21 307.

Allotype: ♀, 20 km S Lancelin, WA, 4.x.1990, S. Barker, SAMA 1 21 308.

Paratypes: WA: 2♂♂, Cervantes, 23.ix.1977, M. Powell, MPWA; 2♂♂, 6♀♀, 45 km N Eneabba, 20.ix.1980, S. Barker & D. J. Williams, SAMA; 2♀♀, 200 m N Ledge Pt T.O., Lancelin Rd, 8.x.1980, S. Barker, SAMA; 1♂, 2♀♀, McDermid Rock, 11.ii.1981, G. J. Keighery, WAMA; 2♂♂, 1♀, Green Head, 27.viii.1981, R. P. McMillan, WAMA; 1♂, 1♀, 2 km N Badgingarra, M. Powell, 15.ix.1984, MPWA; 1♂, Greenough, 26/29.viii.1989, R. P. McMillan, SAMA; 2♂♂, same data as holotype SAMA; 1♂, 10 km S Dongara, 4.ix.1995, S. Barker, SAMA.

Colour

Head coppery. Antennae bronze. Pronotum coppery. Scutellum bronze with blue-green reflections. Elytra yellow with coppery markings coalesced forming a yellow margin two interstices wide; a yellow vitta on each side from base to pre-apical area. Ventral surface coppery. Legs: femora and tibiae coppery; tarsomeres bronze. Hairs silver.

Shape and sculpture

Head closely punctured, median sulcus present, muzzle short. Antennomeres 1-3 obconic, 4-11 toothed. Pronotum closely punctured, small basal fovea extending anteriorly to middle as glabrous line; apical margin projecting medially, basal margin almost straight; laterally parallel-sided at base, angled outwards, rounded to widest at middle, rounded and narrowed to apex. Scutellum scutiform, glabrous, flat. Elytra punctate-striate, intervals convex, wrinkled and punctured more heavily laterally than medially; laterally angled out from base, rounded at humeral callus, concave, rounded post-medially and narrowed to bispinose apex; both spines minute, margin rounded and indented between spines, apices diverging. Ventral surface with shallow punctures, edges of abdominal segments glabrous, elsewhere dense, flat, leathery hairs. *S*₇: males truncate; females rounded.

Size

Males $12.9 \pm 0.24 \times 4.3 \pm 0.08$ mm (12). Females, $13.5 \pm 0.17 \times 4.3 \pm 0.13$ mm (14).

Aedeagus (Fig. 1T1)

Parameres angled outwards from basal piece, rounded apically. Penis sharp, sides acutely angled away. Apophysis of basal piece medium width, rounded apically. Proctiger bilobed, lobes near mid-line, blunt, apical edge straight, rounded laterally (Fig. 1T1).

Female terminalia (Fig. 1T2)

Proctiger as in male, lobes more pronounced.

Remarks

This species can be distinguished from any others in the group by the elytral markings. It is the only species occurring in WA which has all of the yellow elytral spots fused to form an elongate yellow vitta on each elytron. Some specimens have darker red markings on the elytra than others and these tend to fade to dark brown in old specimens. Six specimens of the type series have a long, separate pre-apical yellow mark. All specimens except those collected at McDermid Rocks were taken on the flowers of *Chamaelaucium* sp.

Etymology

The specific name is derived from Gk *charientos*, beautiful.

Castiarina ferruginea sp. nov.
(FIGS 1Q, 1 Q1, 1 Q2, 3H)

Holotype: ♂, Wialki, WA, 18.ix.1957, S. Barker, SAMA I 21 309.

Allotype: ♀, same data as holotype, SAMA I 21 310.

Paratypes: WA: 2♂♂, Wialki, ix.1959, F. H. Uther Baker, WAMA; 1♂, 88 km NE Wubin, 17.ix.1970, S. Barker, SAMA; 1♂, Walyahmoning Rock (30° 38' S 118° 45' E), 9.x.1972, A. Baynes & R. Humphries, WAMA; 3♂♂, 2♀♀, Muckinbudin, 10.x.1979, R. P. McMillan, WAMA; 2♀♀, 8 km E Woolgangie, 22.x.1980, S. Barker & P. G. Kempster, SAMA; 2♂♂, Southern Cross, x.1981, R. P. McMillan, WAMA; 1♀, Johnson Lake, 8.xi.1981, D. Knowles, MPWA; 3♂♂, 1♀, Southern Cross, 8.x.1983, R. P. McMillan, WAMA; 2♂♂, Eneabba, 15.x.1985, R. P. McMillan, WAMA; 1♂, 1♀, Dedari, 20.x.1986, M. Powell, MPWA; 1♂, 30 km E Lake King, 18.xi.1988, M. Powell, MPWA; 2♂♂, 2♀♀, N77 Transmitter, 32 km E Southern Cross, 21.x.1991, T. M. S. Hanlon, MHSA; 2♂♂, 4♀♀, Dedari, 21.x.1991, T. M. S. Hanlon, MHSA; 1♀, Karlgarin, Bessy Tolland, WAMA.

Colour

Head dark coppery with blue-green reflections. Antennae bronze. Pronotum dark coppery with blue-green reflections. Scutellum dark purple. Elytra yellow with dark maroon markings coalesced forming a narrow yellow margin from base to pre-apical area, one interstice wide from base, two interstices wide at humeral callus, two wide pre-medially continuously two wide from post-medially; row of four yellow spots on each side, basal round the remaining three elongate. Ventral surface coppery. Legs: femora and tibiae dark copper, tarsi bronze. Hairs silver.

Shape and sculpture

Head punctured, median sulcus present, muzzle short. Antennomeres 1-3 obconic, 4-11 toothed. Pronotum closely punctured, small basal fovea extending anteriorly to middle as glabrous line; apical margin projecting medially, basal margin almost straight, laterally parallel-sided at base, angled outwards then rounded to widest medially, rounded and narrowed to apex. Scutellum scutiform, elongate, glabrous, excavate. Elytra punctate-striate, intervals convex, punctured and wrinkled, more so laterally than medially; laterally angled out from base, rounded at humeral callus, concave, rounded post-medially and narrowed to unispinose apex; blunt marginal spine, margin indented and straight to suture, apices hardly diverging. Ventral surface with shallow punctures, edges of abdominal segments glabrous, elsewhere with dense, flattened, feathery hair. S₇: males, truncate; females rounded.

Size

Males, 12.3 ± 0.2 × 4.0 ± 0.07 mm (21). Females, 13.2 ± 0.22 × 4.3 ± 0.09 mm (15).

Aedeagus (Fig. 1Q)

Parameres angled outwards from basal piece, pre-medially rounded then shallowly concave, rounded apically. Penis sharp, sides obtusely angled away. Hypophysis of basal piece broad, rounded apically. Proctiger bilobed, bluntly pointed near mid-line, laterally straight (Fig. 1 Q1).

Female terminalia (Fig. 1 Q2)

Proctiger bilobed, strongly pointed near mid-line, laterally straight.

Remarks

The range of this species overlaps with that of *C. ustulata* sp. nov. which is approximately the same colour but smaller. They can be distinguished on the basis of the yellow elytral markings: in *C. ferruginea* there are four yellow spots on each elytron and in *C. ustulata* three, as the first two are fused forming an elongate basal spot and the last two are separate. *C. ferruginea* has a single, large marginal spine at the apex of the elytra and *C. ustulata* has two small spines. The aedeagi are different (Figs 1Q, 1V); both male and female proctigers in both species are strongly lobed, those of males are quite similar in size and shape but proctigers of female *C. ferruginea* are more pointed than in *C. ustulata* which have black pigment spots at the tip of each lobe; these spots are absent in the other species (Figs 1 Q2, 1 V2).

Etymology

The specific name is derived from *L. ferrugineus*, rust-coloured.

Castiarina ustulata sp. nov.
(FIGS 1V, 1 V1, 1 V2, 3F)

Holotype: ♂, 8 km E Woolgangie, WA, 22.x.1980, S. Barker & P. G. Kempster, SAMA I 21 311.

Allotype: ♀, same data as holotype, SAMA I 21 312.

Paratypes: WA: 1♂, Dumbleyung, 5.x.1963, H. Udell, WAMA; 1♂, 1♀, same data as holotype, SAMA; 3♀♀, Wialki, 21.ix.1970, S. Barker, SAMA; 2♂♂, 9 km SW Walyahmoning Rock, 9.x.1972, A. Baynes & R. Humphries, WAMA; 1♂, 18.9 km WSW Coolgardie, 18.ix.1976, R. J. Chinnock, SAMA; 1♀, Dedari, 8.x.1978, T. M. S. Hanlon, WAMA; 1♂, Muckinbudin, 10.x.1979, R. P. McMillan, WAMA;

1 ♀, Southern Cross, x.1981, R. P. McMillan, WAMA; 1 ♂, Bullfinch, 2.x.1983, B. Jones, MPWA; 1 ♂, Southern Cross, 8.x.1983, R. P. McMillan, WAMA; 1 ♀, 28 km NE Peak Charles, 9.x.1983, G. Browning & G. Mutze, SAMA; 1 ♂, 1 ♀, 45 km SW McDermid Rock, 24.x.1985, T. F. Houston & R. W. Thorp, WAMA; 2 ♀ ♀, Dedari, 20.x.1986, M. Powell, MPWA; 1 ♂, Bindoo Hill Nature Reserve, 27 km W Mullewa, 12.ix.1987, T. F. Houston, WAMA; 4 ♂ ♂, 2 ♀ ♀, N7T Transmitter, 37 km E Yellowline, 21.x.1991, T. M. S. Hanlon, MHSA; 2 ♂, 4 ♀ ♀, Dedari 22.x.1991, T. M. S. Hanlon, MHSA; 3 ♂ ♂, 1 ♀, Karlgarin, Bessy Tolland, WAMA.

Colour

Head coppery. Antennae bronze. Pronotum coppery. Scutellum blue. Elytra yellow with brown markings with coppery reflections coalesced and forming a yellow margin from base to pre-apical area, one interval thick medially, two intervals thick elsewhere; three medial yellow marks on each side with an elongate basal mark formed from the fusion of the basal and pre-medial marks, round post-medial mark and elongate pre-apical mark. Ventral surface either all coppery or with coppery sternum and coppery-brown abdomen with blue reflections. Legs: femora coppery; tibiae and tarsi bronze. Hairs silver.

Shape and sculpture

Head closely punctured, median sulcus present, muzzle short. Antennomeres 1-3 obconic, 4-11 toothed. Pronotum closely punctured, small basal fovea extending anteriorly to middle as impressed line; apical margin projecting medially, basal margin almost straight; laterally parallel-sided at base, rounded to widest pre-medially, rounded and narrowed to apex. Scutellum scutiform, glabrous, excavate. Elytra punctate-striate, intervals convex, punctured and wrinkled, more so laterally than medially; laterally angled out from base, rounded at humeral callus, concave, rounded post-medially and narrowed to bispinose apex; sharp marginal spine, minute sutural spine, margin rounded and indented between spines, apices hardly diverging. Ventral surface with shallow punctures, edges of abdominal segments glabrous, elsewhere dense flattened, feathery hairs. S_7 : males truncate; females rounded.

Size

Males, $12.1 \pm 0.15 \times 3.9 \pm 0.05$ mm (20). Females, $12.7 \pm 0.19 \times 4.0 \pm 0.07$ mm (18).

Aedeagus (Fig. 1V)

Parameres parallel-sided from basal piece, angled outwards pre-medially, rounded apically. Penis sharp, sides acutely angled away. Hypophysis of basal piece

medium width, apically rounded. Proctiger bilobed, lobes near mid-line, blunt, apical edge straight, laterally rounded (Fig. 1VI).

Female terminalia (Fig. 1V2)

Proctiger bilobed, lobes near mid-line, blunt, each with a dark pigment spot at tip, apical edge straight, laterally rounded, hairless.

Remarks

See remarks under *C. ferruginea*. Elytral markings are the same in this species as in *C. antarctica* sp. nov. but they have non-overlapping ranges. The aedeagus in *C. antarctica* is shorter and broader than that in *C. ustulata* (Figs. 1O, 1V). The proctigers of both sexes in *C. ustulata* are bilobed with more highly developed lobes than those in *C. antarctica* (Figs 1O1, 1O2, 1V1, 1V2).

Etymology

The specific name is derived from *L. ustulatus*, scorched.

Castlarina phaeopus sp. nov.
(FIGS 1W, 1W1, 1W2, 3E)

Holotype: ♂, 3 km E Gosnells, WA, 4.xi.1956, S. Barker, SAMA 121 313.

Allotype: ♀, Red Hill, WA, 2.ix.1949, R. P. McMillan, SAMA 121 314.

Paratypes: WA: 3 ♂ ♂, 1 ♀, no data, SAMA; 2 ♂ ♂, Swan R., Lea, SAMA; 1 ♀, Bunbury, W. M. Mack, i.1898, SAMA; 2 ♀ ♀, Perth, xi.1906, SAMA; 2 ♂ ♂, 1 ♀, Perth, x.1913, SAMA; 4 ♂ ♂, Perth, xi.1920, J. W. Mellor, SAMA; 1 ♂, 1 ♀, same data as allotype, SAMA; 1 ♂, Mimmgarra, Dandaragan, 30.x.1955, S. Barker, SAMA; 2 ♂ ♂, 2 km E Gosnells, 4.xi.1956, S. Barker, SAMA; 15 ♂ ♂, same data as holotype, SAMA; 2 ♂ ♂, summit Mt Cooke, 10.xi.1956, S. Barker, SAMA; 1 ♂, 1 ♀, 70 km SE Perth on Albany Hwy, 10.xi.1956, S. Barker, SAMA; 1 ♂, foothills Kelmscott, 21.x.1958, J. Baldwin, SAMA; 3 ♂ ♂, 2 ♀ ♀, Wilga, 26.x.1972, K. & E. Carnaby, SAMA; 2 ♂ ♂, Lesmurdie, 28.ix.1955, J. A. Watson, SAMA; 1 ♀, Julimar Forest, 24.x.1971, E. H. Uther Baker, SAMA; 6 ♂ ♂, 3 ♀ ♀, Cataby Bk, 18.x.1983, G. Browning & G. Mutze, SAMA; 1 ♂, Gosnells, 7.x.1980, S. Barker, SAMA; 1 ♂, Mundaring Weir, 30.ix.1980, T. M. S. Hanlon, MHSA; 1 ♀, Mt Dale, 29.ix.1980, T. M. S. Hanlon, MHSA.

Colour

Head brown with coppery reflections. Antennae bronze. Pronotum brown with coppery reflections.

Scutellum coppery with blue reflections. Elytra yellow with the following markings: narrow blue basal margin, other markings blue with coppery reflections coalesced leaving a yellow margin from base to apex from one to two intervals wide and two yellow marks in the middle of each elytron in the form of an elongate basal vitta formed by the fusion of the first three spots and an elongate pre-apical mark. Ventral surface coppery. Legs: femora coppery; tibiae and tarsi bronze. Hairs silver.

Shape and sculpture

Head closely punctured, median sulcus present, muzzle short. Antennomeres 1-3 obconic, 4-11 toothed. Pronotum closely punctured basal fovea extending forwards to middle as impressed line; apical margin projecting medially, basal margin almost straight; laterally parallel-sided at base, angled outwards, rounded medially at widest part, rounded and narrowed to apex. Scutellum scutiform, glabrous, flat. Elytra punctate-striate, intervals convex, punctured and wrinkled laterally, punctured and smooth medially; laterally angled out from base, rounded at humeral callus, concave, rounded post-medially, narrowed to bispinose apex; very small sharp spines, margin rounded and indented between spines, apices hardly diverging. Ventral surface with shallow punctures, edges of abdominal segments glabrous, elsewhere dense flattened, feathery hairs. S_7 : males truncate; females rounded.

Size

Males, $11.1 \pm 0.11 \times 3.7 \pm 0.05$ mm (51). Females, $11.5 \pm 0.35 \times 3.8 \pm 0.12$ mm (12).

Aedeagus (Fig. 1W)

Parameres angled outwards from basal piece, apically rounded. Penis sharp, sides acutely angled away. Hypophysis of basal piece medium width, apically rounded. Prætiger with small medial notch in apical edge, laterally rounded (Fig. 1W1).

Female terminalia (Fig. 1W2)

Prætiger bilobed, apical edge straight, laterally rounded.

Remarks

C. phaeopus sp. nov. can be distinguished from all others in this complex by being the only species which has the first three elytral yellow spots fused to form an elongate basal mark with the fourth an elongate pre-apical yellow mark.

Etymology

The specific name is derived from Gk *phaios*, brown.

Castiarina antarctica sp. nov. (FIGS 10, 1 O1, 1 O2, 3D)

Holotype: ♂, 64 km NE Esperance, WA, 18.x.1982, S. Barker, P. G. Kempster & H. Vanderwoude, SAMA I 21 315.

Allotype: ♀, same data as holotype, SAMA I 21 316.

Paratypes: WA: 1 ♂, Mt Ragged, 24.x.1980, S. Barker & P. G. Kempster, SAMA; 1 ♂, 13 km N Israelite Bay, 24.x.1980, S. Barker & P. G. Kempster, SAMA. 1 ♂, 2 ♀ ♀, 24 km N Israelite Bay, 24.x.1980, S. Barker & P. G. Kempster, SAMA; 1 ♂, same data as holotype, SAMA; 5 ♂ ♂, 7 km N Dempster Rd Scadden Rd crossing, Esperance district, 18.x.1982, S. Barker, P. G. Kempster & H. Vanderwoude, SAMA; 2 ♂ ♂, 2 ♀ ♀, Parmangoes Rd 2 km NE Clyde Hill T.O., Esperance district, S. Barker, P. G. Kempster & H. Vanderwoude, SAMA; 1 ♀, Israelite Bay, 21.x.1982, S. Barker, P. G. Kempster & H. Vanderwoude, SAMA; 2 ♂ ♂, 1 ♀, 17 km NW Israelite Bay, 21.x.1982, S. Barker, P. G. Kempster & H. Vanderwoude, SAMA.

Colour

Head coppery. Antennae bronze. Pronotum dark bronze medially, with coppery reflections laterally. Scutellum coppery-purple. Elytra yellow with the following dark brown markings with coppery reflections coalesced leaving yellow margin, two intervals wide at apex and at humeral callus, one interval wide medially; a row of yellow spots medially on each elytron. basal and pre-medial coalesced forming an elongate mark, post-medial more or less round, apical smaller and elongate. Ventral surface coppery. Legs: femora dull purple with coppery reflections; tibiae and tarsi bronze. Hairs silver.

Shape and sculpture

Head closely punctured, median sulcus narrow, muzzle short. Antennomeres 1-3 obconic, 4-11 toothed. Pronotum closely punctured, small basal fovea extending forward to middle as glabrous line; apical margin projecting medially, basal margin almost straight; laterally parallel-sided at base, rounded to widest pre-medially, narrowed to apex. Scutellum scutiform, flat, glabrous. Elytra punctate-striate, intervals convex, punctured and wrinkled laterally and apically, smooth medially; laterally angled out from base, rounded at humeral callus, concave, rounded post-medially and narrowed to bispinose apex; very small marginal spine, minute medial spine, margin rounded and indented between spines, apices divergent. Ventral surface with shallow punctures, edges of abdominal segments glabrous, elsewhere densely hairy, hairs flat and feathery. S_7 : males truncate; females rounded.

Size

Males, $12.0 \pm 0.19 \times 3.9 \pm 0.06$ mm (14). Females, $12.0 \pm 0.22 \times 4.0 \pm 0.09$ mm (7).

Aedeagus (Fig. 1 O)

Parameres angled outwards from basal piece, rounded pre-medially, parallel-sided post-medially, rounded at apex. Penis sharp, sides acutely angled away. Hypophysis of basal piece medium width, apically rounded. Proctiger bilobed, lobes bluntly pointed near mid-line, laterally straight (Fig. 1 O1).

Female terminalia (Fig. 1 O2)

Proctiger bilobed, lobes blunt near mid-line, laterally straight.

Remarks

The remarks made under those for *C. ustulato* sp. nov. apply equally to this species as these are the only two species in this complex which have this elytral pattern. They can be easily distinguished by differences in aedeagi (Figs 1 O, 1 V) and in male and female proctigers (Figs 1 O1, 1 O2, 1 V1, 1 V2). Also they are allopatric.

Etymology

The name is derived from Gk *antarktikos*, southern

Castiarina nonyma sp. nov.
(FIGS 1X, 1 X1, 1 X2, 3A)

Holotype: ♂, Summit Mt Cooke, WA, 10.xi.1956, S Barker, SAMA 1 21 317.

Allotype: ♀, Julimar Forest, WA, 24.x.1971, E. H. Uther Baker, SAMA 1 21 318.

Paratypes: WA: 2♂♂, 2♀♀, Beverley, E. F. du Boulay, SAMA; 2♂♂, Perth, SAMA; 1♂, Swan R., SAMA; 1♀, xii.1913, SAMA; 2♂♂, same data as holotype, SAMA; 1♂, Mt Walker (32°05' S 118°45' E) 16.x.1979, R. P. McMillan, WAMA; 1♂, Gosnells, 7.x.1980, S. Barker, SAMA; 1♀, Forrestfield, 27.viii.1978, T. M. S. Hanlon, WAMA; 1♀, Eneabba, 17.x.1985, R. P. McMillan, WAMA.

Colour

Head and antennae dark maroon, Pronotum dark maroon with blue reflections medially, Scutellum dark maroon. Elytra yellow with maroon markings coalesced to form yellow margins, two intervals wide at humeral callus and apically, one interval wide medially; a medial row of four yellow spots on each elytron, basal and post-medial more or less round, pre-medial and pre-apical elongate, in about a quarter of the

specimens examined the first two coalesced forming an elongate basal yellow mark. Ventral surface maroon. Legs: femora maroon; tibiae maroon proximally, bronze medially; tarsi bronze. Hairs silver.

Shape and sculpture

Head closely punctured, median sulcus shallow, muzzle short. Antennomeres 1-3 obconic, 4-11 toothed. Pronotum closely punctured, small basal fovea extending forwards to middle as impressed line; apical margin projecting medially, basal margin almost straight; laterally parallel-sided at base, rounded to widest medially, rounded and narrowed to apex. Scutellum scutiform, glabrous, excavate. Elytra punctate-striate, intervals convex punctured and wrinkled laterally and apically, smooth medially; laterally angled out from base, rounded at humeral callus, concave, rounded post-medially and narrowed to unispinose apex; small, blunt marginal spine, margin straight and indented to suture, apices diverging. Ventral surface with shallow punctures, edges of abdominal segments glabrous, elsewhere with dense flat, feathery hair. S_7 : males truncate; females rounded.

Size

Males, $11.0 \pm 0.28 \times 3.5 \pm 0.09$ mm (10). Females, $11.1 \pm 0.24 \times 3.7 \pm 0.07$ mm (6).

Aedeagus (Fig. 1 X)

Parameres angled outwards from basal piece, slightly rounded post-medially then angled outwards, apically rounded. Penis sharp, sides acutely angled away. Hypophysis of basal piece medium width, apically rounded. Proctiger with medial apical edge straight, then angled forming two small broadly pointed lobes, laterally rounded (Fig. 1 X1).

Female terminalia (Fig. 1 X2)

Proctiger bilobed, medial apical margin faintly concave, lobes small and broadly pointed, laterally rounded.

Remarks

No female specimens associated with males at the same collection locality were available. This and the following species *C. enigma* sp. nov. have elytra predominantly eight spotted, although a small number of each has the first two spots coalesced. The two species can be distinguished by differences in aedeagi which are short and broad in *C. enigma* and elongate in *C. nonyma* (Figs 1X, 1V) and in male and female proctigers which are virtually unsculptured in *C. enigma* and bilobed with pointed lobes in *C. nonyma* (Figs 1 X1, 1 X2, 1 Y1, 1 Y2). The distribution of *C. nonyma* appears to be mainly to the east of the Darling Scarp fault line, while that of *C. enigma* is to the west of the Darling Scarp on the coastal Plain.

Etymology

The name is derived from Gk *anonymos*, unknown

Castiarina enigma sp. nov.
(FIGS 1Y, 1 Y1, 1 Y2, 3C)

Holotype: ♂, Regans Ford, WA, 9.x.1970, K. & E. Carnaby, SAMA 1 21 319.

Allotype: ♀, 6 km S Gin Gin, WA, 30.ix.1956, S. Barker, SAMA 1 21 320.

Paratypes: WA: 1♂, 1♀, no data, SAMA; 1♂, E Ashby, SAMA; 1♀, Perth, SAMA; 1♀, Perth xi.1905, SAMA; 2♂♂, Perth, xi.1913, SAMA; 2♂♂, 1♀, same data as allotype, SAMA; 8♂♂, 1♀, same data as holotype, SAMA.

Colour

Head and antennae dark maroon with blue reflections. Pronotum dark maroon, with blue reflections medially. Scutellum dark maroon with blue reflections. Elytra yellow with brown markings with coppery reflections coalesced leaving a yellow margin two intervals wide at humeral callus and apically, one interval wide medially; row of four medial yellow spots on each elytron, basal and post-medial more or less round, pre-medial and pre-apical elongate. Ventral surface and legs coppery. Hairs silver.

Shape and sculpture

Head closely punctured, median sulcus shallow, muzzle short. Antennomeres 1-3 obconic, 4-II toothed. Pronotum closely punctured, narrow basal fovea extending forwards to middle as glabrous line; apical margin projecting medially, basal margin rounded from base to widest medially, rounded and narrowed to apex. Scutellum scutiform, glabrous, flat. Elytra punctate-striate, intervals convex, punctured and wrinkled laterally smooth medially; laterally angled out from base, rounded at humeral callus, concave, rounded post-medially and narrowed to bispinose apex; small, blunt marginal spine, minute sutural spine, margin rounded and indented between spines, apices diverging. Ventral surface with shallow punctures, edges of abdominal segments glabrous, elsewhere densely hairy, hairs flat and feathery. S_7 : males truncate; females rounded.

Size

Males, $10.7 \pm 0.17 \times 3.4 \pm 0.06$ mm (15). Females, $11.8 \pm 0.37 \times 4.0 \pm 0.13$ mm (6)

Aedeagus (Fig. 1Y)

Broad. Parameres angled outwards from basal piece, rounded apically. Penis sharp, sides obtusely angled

away. Apophysis of basal piece medium width, apically rounded. Proctiger broadly rounded at apex, sides rounded (Fig. 1 Y1).

Female terminalia (Fig. 1 Y2)

Proctiger rounded.

Remarks

The remarks under *C. nonyma* apply equally to this species.

Etymology

The name is derived from L. *aenigma*, mystery.

Castiarina aura sp. nov.
(FIGS 1S, 1 S1, 1 S2, 3I)

Holotype: ♂, 131 km S Exmouth, WA, 12.ix.1984, M. Powell, WAMA.

Allotype: ♀, same data as holotype, WAMA.

Paratypes: WA: 1♀, 50 km N Kalbarri T.O., 20.viii.1978, T. M. S. Hanlon, WAMA; 1♂, Yardi Ck, 18.viii.1983, M. Powell, MPWA; 1♂, Coral Bay, 10.ix.1984, M. Powell, MPWA; 1♂, 1♀, Carnarvon, 28.viii.1987, A. Hay, SAMA; 1♀, 94 km S Learmonth, 2.ix.1995, Powell & Kershaw, MPWA; 1♀, 62 km S Learmonth, 4.ix.1995, MPWA; 1♂, 1♀, 26 km S Learmonth, 3.ix.1995, Powell & Kershaw, MPWA.

Colour

Head coppery. Antennae bronze with coppery reflections. Pronotum coppery, with medial blue-green reflections. Scutellum blue-green. Elytra yellow with the following elytral markings; markings coalesced, coppery apically, with blue-green reflections along the suture and over the humeral callus forming a yellow margin two intervals wide, medial row of four yellow spots on each elytron, basal and post-medial more or less round, pre-medial and pre-apical elongate. Ventral surface and legs coppery. Hairs silver.

Shape and sculpture

Head closely punctured, median sulcus shallow, muzzle short. Antennomeres 1-3 obconic, 4-II toothed. Pronotum closely punctured, basal fovea extending forwards to middle as glabrous line; apical margin projecting medially, basal margin almost straight; laterally parallel-sided at base, rounded to widest before middle, rounded and narrowed to apex. Scutellum scutiform, wrinkled, excavate. Elytra punctate-striate, intervals convex, punctured and wrinkled laterally, smooth medially; laterally angled outwards from base

rounded at humeral callus, concave, rounded after middle, tapered to unispinose apex; marginal spine rounded, margin rounded and indented to suture, apices diverging. Ventral surface with shallow punctures, edges of abdominal segments glabrous, elsewhere dense, flat, feathery hairs. S_7 : males truncate; females rounded.

Size

Male, $11.9 \pm 0.42 \times 4.0 \pm 0.15$ mm (5). Females, $12.9 \pm 0.44 \times 4.3 \pm 0.18$ mm (6).

Aedeagus (Fig. 1S)

Parameres angled outwards from basal piece, rounded post-medially, parallel-sided, rounded at apices. Penis sharp, sides acutely angled away. Apophysis of basal piece wide, apically rounded. Proctiger bilobed, lobes blunt (Fig. 1S).

Female terminalia (Fig. 1S2)

Proctiger bilobed, lobes strongly pointed near mid-line.

Remarks

C. aura sp. nov. and *C. ferruginea* sp. nov. are similar in that both have four separate yellow spots on each elytron and a large single marginal spine on the apices of the elytra although the elytral colour is different, *C. aura* being red with green reflections while *C. ferruginea* is brownish. Aedeagi differ as they are shorter and narrower in *C. aura* than they are in *C. ferruginea* (Figs 1Q, 1S). The proctigers of *C. ferruginea* males are strongly bilobed while those of *C. aura* are faintly bilobed (Figs 1Q1, 1S1). The proctigers of females of both species are bilobed and pointed but the lobes are further apart in *C. aura* than they are in *C. ferruginea* (Figs 1Q2, 1S2).

Etymology

The name is derived from *L. aura*, glow.

Key to WA species of *C. parallela* complex

- | | |
|---|-----------------------------|
| 1. Elytra background colour dark blue | 2 |
| Elytra background colour brown, red or green | 3 |
| 2. Elytra with 8 round, yellow marks | <i>betapunctata</i> Barker |
| Elytra with 2 round, 6 elongate yellow marks | <i>azurea</i> sp. nov. |
| 3. Elytra bright red or partially or wholly brassy green | 4 |
| Elytra brown or red-brown | 6 |
| 4. Elytra bright red, elytral apices with two small spines, elytral spots coalesced into single elongate yellow mark on each side | <i>chariemessa</i> sp. nov. |
| Elytra bright red or partially or wholly brassy green, elytra with 8 yellow spots | 5 |

- | | |
|--|-----------------------------|
| 5. Elytral apices with 1 large spine | <i>aura</i> sp. nov. |
| Elytral apices with 2 small, blunt spines | <i>croccicolor</i> (L. & G) |
| 6. Some elytral marks coalesced forming 6 or fewer yellow marks | 7 |
| Elytra with 8 yellow marks | 10 |
| 7. First 3 yellow marks on each elytron coalesced, forming 1 elongate anterior mark and 1 small elongate mark posteriorly on each side | <i>phaeopus</i> sp. nov. |
| First 2 yellow marks on each elytron coalesced, forming 1 elongate anterior mark and 2 small elongate marks posteriorly on each side | 8 |
| 8. Pronotum bronze, elytra dull brown, male proctiger slightly sculptured, female proctiger unsculptured. Largest member of group. | <i>adusta</i> sp. nov. |
| Pronotum, elytra with coppery reflections | 9 |
| 9. Proctiger bilobed, lobes pointed, in females with pigment spot at tip | <i>ustulata</i> sp. nov. |
| Proctiger medially notched, lobes blunt without pigment in females | <i>antarctica</i> sp. nov. |
| 10. Elytral apices with single large spine | <i>ferruginea</i> sp. nov. |
| Elytral apices bispinose | 11 |
| 11. Aedeagus broad, proctiger unsculptured in both sexes | <i>enigma</i> sp. nov. |
| Aedeagus narrow, proctiger sculptured in both sexes | <i>nonyma</i> sp. nov. |

Castiarina nullarborica sp. nov. (FIGS 1J, 4D)

Holotype: ♂, 5 km E Eucla, WA, 28.x.1989, K. L. Walker, NMVA.

Allotype: ♀, Nullarbor Plain, SA, SAM A 1 21 321.

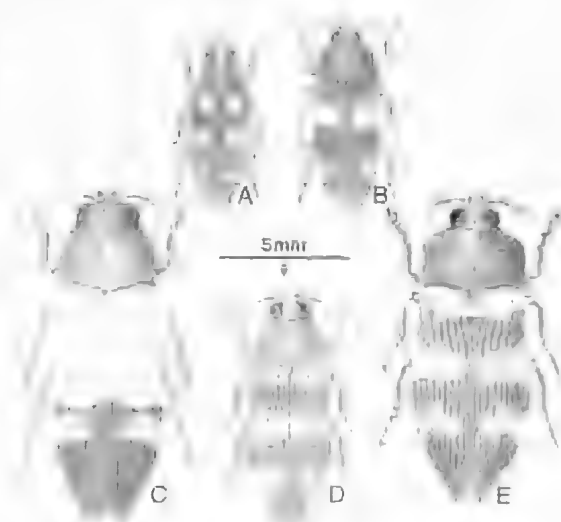


Fig. 4. Habitus illustrations of the following *Castiarina* species. A. *Castiarina jackhasenpuschi* sp. nov. holotype. B. *C. hemizosteria* sp. nov. holotype. C. *C. paulhasenpuschi* sp. nov. holotype. D. *C. nullarborica* sp. nov. holotype. E. *C. demarzi* sp. nov. allotype.

Paratypes: SA: 1♂, 32 km E Eucla, 11.xii.1984, M. Powell, MPWA. WA: 1♂, same data as holotype, SAMA.

Colour

Head dark blue. Antennae blue-green. Pronotum bronze medially, dark blue laterally. Scutellum dark blue. Elytra yellow with red margin and the following black markings with blue reflections: narrow basal margin; broad pre-medial fascia not reaching margin, distally angled anteriorly; broad post-medial fascia reaching margin; spade-shaped apical mark covering apex and spines, last two marks connected broadly along suture. Ventral surface bronze. Legs dark blue. Hairs silver.

Shape and sculpture

Head closely punctured, median sulcus broad, muzzle short. Antennomeres 1-4 obconic, 5-II toothed. Pronotum closely punctured, small basal fovea; apical margin straight, basal margin bisinuate; laterally parallel-sided at base, rounded to widest pre-medially, rounded and narrowed to apex. Scutellum scutiform, glabrous, flat. Elytra punctate-striate, intervals convex, punctured; laterally angled out from base, rounded at humeral callus, concave, rounded post-medially and narrowed to bispinose apex; sharp marginal spine, small, sharp sutural spine, margin rounded and deeply indented between spines, apical margin subserrate. Ventral surface with shallow punctures, edges of abdominal segments glabrous, elsewhere moderately hairy, hairs medium length. S_7 : truncate in both sexes. Male legs 2-3; pulvilli absent on tarsomeres 1-3 replaced with a small double, median spine.

Size

Males, 9.2 x 3.5 mm (3). Female, 10.6 x 4.5 mm (1).

Aedeagus (Fig. 1J)

Wedge-shaped.

Remarks

This species is closest to the morph of *C. placida* (Thomson) which has a red margin and occurs on the west coast of WA and on Rottnest Is., WA. *C. nullarborica* is a smaller species than *C. placida* and the male genitalia differ in size and shape (Figs 1I, 1J).

Etymology

The name is derived from Nullarbor Plain, the area where this species occurs.

Castiarina demarzi sp. nov.
(FIGS 1H, 4E)

Holotype: ♂, Eurardy HS (27°34'S, 114°40'E) WA, 19.viii.1980, C. A. Howard & T. F. Houston, WAMA.

Allotype: ♀, 36 km NE Tamala Station, Shark Bay, WA, 28.ix.1988, D. Knowles, WAMA.

Paratypes: WA: 1♀, same data as allotype, MPWA; 1♀, 26 km NE Tamala Station, 6.x.1988, D. Knowles, SAMA; 1♀, found in seed collection from NW coast, 29.viii.1986, H. Demarz, HDWA.

Colour

Head, antennae and pronotum bronze with or without coppery reflections. Scutellum blue or bronze. Elytra yellow with the following black markings with blue reflections: narrow basal margin; pre-medial fascia not reaching margin, distally angled anteriorly; post-medial fascia reaching margin, projecting anteriorly in middle of each elytron; mark covering whole apex, marks connected along suture in holotype but not allotype. Ventral surface and legs coppery. Hairs silver.

Shape and sculpture

Head closely punctured, median sulcus broad, muzzle very short. Antennomeres compressed, 1-3 obconic, 4-II toothed. Pronotum closely punctured, basal fovea extending anteriorly to middle as glabrous line, basal notches represented by glabrous area on each side closer to margin than middle; apical margin projecting medially, basal margin barely bisinuate; laterally angled outwards from base, rounded to widest after middle, rounded and narrowed to apex. Scutellum scutiform, glabrous, flat. Elytra punctate-striate, intervals convex, punctured; laterally angled out from base, rounded at humeral callus, concave, rounded post-medially and narrowed to bispinose apex; sharp marginal spine, small, sharp sutural spine, apices diverging, apical margin subserrate. Ventral surface with shallow punctures, edges of abdominal segments glabrous, elsewhere short sparse hair. S_7 : male truncate; females rounded.

Size

Male, 10.0 x 3.7 mm (1). Females, 11.7 ± 0.22 x 4.6 ± 0.11 mm (4).

Aedeagus (Fig. 1H)

Parameres parallel-sided from basal piece, rounded pre-medially then narrowed to apex. Penis blunt, sides acutely angled away. Hypophysis of basal piece medium width, apically rounded.

Remarks

The structure and elytral markings of this species resemble *C. bucolica* (Kerremans). However *C. bucolica* has head, pronotum and ventral surface green and there are size differences between aedeagi, that of *C. demarzi* being smaller than that of *C. bucolica* (Figs 1G, 1H).

Etymology

The name honours Mr Herbert Demarz, Guilderton, who has generously assisted my research by loaning specimens for many years.

Castiarina jackhasenpuschi sp. nov.
(FIGS 1L, 4A)

Holotype: ♂, Cardwell Rd., Qld, 22.xii.1995, J. Hasenpusch, SAMA I 21 322.

Allotype: ♀, Cardwell Rd., Qld, 22.xii.1995, P. Hasenpusch, SAMA I 21 323.

Colour

Head reddish-bronze, muzzle green-bronze. Antennae green. Pronotum reddish-bronze with a curved blue bar, concave inwards, on each side of the mid-line from base to apex. Scutellum green with yellow reflections. Elytra yellow with the following black markings: broad basal margin; broad pre-medial fascia with ends expanded anteriorly reaching basal margin and posteriorly reaching margin enclosing a yellow basal spot and a yellow spot on margin at humeral callus; broad post-medial fascia reaching margin and mark covering whole apex; yellow medial fascia not reaching margin; yellow post-medial fascia not reaching suture or margin; ventral surface green with yellow reflections, legs blue-green. Hairs silver.

Shape and sculpture

Head closely punctured, median sulcus present, muzzle short. Antennomeres 1-3 obconic, 4 half-toothed, 5-11 toothed. Pronotum closely punctured, small basal fovea; apical margin straight, basal margin bisinuate; laterally angled inwards from base, rounded, widest before middle, rounded and narrowed to apex. Scutellum scutiform, punctured, flat. Elytra punctate-striate, intervals convex, punctured; laterally angled out from base, rounded at humeral callus, concave, rounded post-medially, narrowed to bispinose apex; large sharp marginal spine, minute sutural spine, margin indented and straight between spines, apices hardly diverging. Ventral surface with shallow punctures, edges of abdominal segments glabrous, elsewhere sparse very short hairs. S_7 : male rounded; female slightly rounded and turned under.

Size

Male, 6.4 x 2.5 mm (l). Female, 6.9 x 2.6 mm (l).

Aedeagus (Fig. 1L)

Narrow and elongate. Parameres angled inwards from basal piece, parallel-sided, rounded at apex. Penis sharp, sides acutely angled away. Apophysis of basal piece wide, apically rounded.

Remarks

This species superficially resembles *C. cydista* (Rainbow). It is however, smaller, the structure of the antennomeres differs as the 4th antennomere of *C. cydista* is fully toothed and male genitalia are dissimilar (Figs 1K, 1L).

Etymology

This species is named to honour Mr J. Hasenpusch, Innisfail, who has generously supported my research by loaning specimens and providing information.

Castiarina paulhasenpuschi sp. nov.
(FIGS 1F, 4C)

Holotype: ♂, Marsupial Ck near Croydon, Qld, 2.vi.1995, P. Hasenpusch, SAMA I 21 324.

Allotype: ♀, same data as holotype, SAMA I 21 325.

Paratypes: Qld: 1 ♀, same data as holotype JHQA; 2 ♂♂, Marsupial Ck, 1-15 iv.1995, P. Hasenpusch, JHQA; 1 ♂, 1 ♀, Marsupial Ck, 2.vi.1995, J. Hasenpusch, JHQA.

Colour

Head, bronze. Antennae bronze with green reflections. Pronotum bronze, laterally with green reflections. Scutellum green. Elytra yellow with the following black markings with blue reflections: narrow basal margin, in the holotype a mark covering most of apical half in form of a post-medial fascia connected to the apical mark leaving a pre-apical yellow spot on each margin; in one specimen the fascia is reduced to two small black spots on the margin. Ventral surface and legs green. Hairs silver.

Shape and sculpture

Head closely punctured, glabrous, median sulcus present, muzzle very short. Antennomeres compressed, 1-3 obconic, 4-11 toothed. Pronotum closely punctured, glabrous, basal fovea extending forwards but not reaching middle, basal notches on each side closer to margin than middle; apical margin projecting medially, basal margin bisinuate; laterally parallel-sided at base, rounded to widest at middle, rounded to apex. Scutellum scutiform, glabrous, excavate. Elytra punctate-striate, intervals convex, more so apically; laterally angled out from base, rounded at humeral callus, concave, rounded post-medially, narrowed to bispinose apex; sharp marginal spine, small sharp sutural spine, margin indented and rounded between spines, apices diverging, apical margin strongly sub-serrate. Ventral surface with shallow punctures, edges of abdominal segments glabrous,

elsewhere moderately hairy, hairs medium length. S_7 : males truncate; females bilobed, each lobe with four claws.

Size

Males, $13.2 \pm 0.16 \times 4.5 \pm 0.07$ mm (4). Females, $13.5 \pm 0.45 \times 4.7 \pm 0.18$ mm (3).

Aedeagus (Fig. 1F)

Parameres parallel-sided from basal piece, rounded medially, parallel-sided, rounded to apex. Penis sharp, sides obtusely angled away. Apophysis of basal piece medium width, apically rounded.

Remarks

The distinct colour and pattern of this species distinguish it from all other species, as does the structure of the last visible abdominal segment in females, in which the claws are unique. The specimens examined were all caught by use of a colour lure in an area where no plants were flowering.

Etymology

The species name honours Master Paul Hasenpusch its discoverer.

Castiarina hemizostera sp. nov. (FIGS 1N, 4B)

Holotype: ♂, Cardwell Ra., Qld, 22.xii.1995, J. Hasenpusch, SAMA I 21 326.

Allotype: ♀, Cardwell Ra., Qld, 24.xii.1993, J. Hasenpusch, SAMA I 21 327.

Paratypes: Qld: 1♂, Cardwell Ra., 19.xii.1995, J. Hasenpusch, JHQA; 2♂♂, same data as holotype, JHQA; 1♂, 1♀, 22.xii.1995, P. Hasenpusch, JHQA; 3♂♂, 30.xii.1995, J. Hasenpusch, JHQA.

Colour

Head black with blue-green reflections, muzzle blue. Antennae green. Pronotum with purple-green reflections medially, blue-green laterally. Scutellum green. Elytra yellow: with black markings with blue-green and/or purple reflections coalesced leaving the following yellow marks: pre-medial yellow fascia reaching margin but not suture, broad pre-apical yellow fascia reaching margin but not suture. Ventral surface black with bronze reflections. Legs blue. Hairs silver.

Shape and sculpture

Head closely punctured, median sulcus broad, muzzle short. Antennomeres 1-3 obconic, 4-11 toothed. Pronotum heavily punctured, basal fovea extending forwards to apical margin as impressed line; apical margin straight, basal margin bisinuate; laterally parallel-sided at base, rounded to widest pre-medially, rounded and narrowed to apex. Scutellum scutiform, punctured, flat. Elytra punctate-striate, intervals convex, heavily punctured; laterally angled out from base, rounded at humeral callus, concave, rounded post-medially and narrowed to bispinose apex; sharp marginal spine, minute sutural spine. margin rounded and indented between spines, apices diverging. Ventral surface with shallow punctures, edges of abdominal segments glabrous, elsewhere moderately hairy, hairs short. S_7 : males truncate; females rounded.

Size

Males, $7.0 \pm 0.2 \times 2.5 \pm 0.09$ mm (8). Females, 7.9×3.0 mm (2).

Aedeagus (Fig. 1N)

Parameres angled outwards from basal piece, rounded and widened post-medially, rounded at apex. Penis sharp, sides acutely angled away. Apophysis of basal piece wide, apically rounded.

Remarks

This species is allied to *C. bella* (Saunders) and is closest to *C. aglaia* (Barker). However, the post-medial fascia in *C. aglaia* is red and the male genitalia differ. (Figs 1M, 1N)

Etymology

The name is derived from Gk *hemisys*, half, Gk *zoster*, belt.

Acknowledgments

I am indebted to the following for assistance: Dr T. F. Houston, WAMA; Dr K. Walker, NMVA; Mr T. Weir, ANIC; Dr E. G. Matthews, SAMA; Mr D. J. Williams, Mr P. G. Kempster and Ms H. Vanderwoude, Department of Zoology, University of Adelaide. I am indebted to the following collectors for the loan and gift of specimens: Dr F. H. Uther Baker, Cottesloe; Mr H. Demarz, Guilderton; Mr T. M. S. Hanlon, Hunters Hill; Mr J. Hasenpusch, Innisfail; Mr R. P. McMillan, Kallaroo; Mr M. Powell, Melville; Mr S. Watkins, Caparra.

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**A NEW GENUS AND THREE NEW SPECIES OF
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*BY PETER KOLESIK**

Summary

Kolesik, P. (1996) A new genus and three new species of Cecidomyiidae (Diptera) from Olearia spp. (Asteraceae) in Australia. Trans. R. Soc. S. Aust. 120(2), 61-67, 31 May, 1996.

A new gall midge genus, *Trigonomyia*, and three new species, *T. ananas* from *Olearia ramulosa* (Labill.) Benth., *T. cristata* and *T. tulipa* both from *O. axillaris* (DC.) F. Muell. Ex Benth., are described. Detailed descriptions of the adults, larvae, pupae and galls are given. The species are distinguished from each other by both their morphology and the appearance of their galls. The new genus is diagnosed and placed in the tribe Oligotrophini within the supertribe Lasiopteridi of the subfamily Cecidomyiinae.

Key Words: Cecidomyiidae, *Trigonomyia ananas* sp. nov., *Trigonomyia cristata* sp. nov., *Trigonomyia tulipa* sp. nov., *Olearia ramulosa*, *Olearia axillaris*, South Australia.

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A new gall midge genus, *Trigonomyia*, and three new species, *T. ananas* from *Olearia ramulosa* (Labill.) Benth., *T. cristata* and *T. tulipa* both from *O. axillaris* (DC.) F. Muell. ex Benth., are described. Detailed descriptions of the adults, larvae, pupae and galls are given. The species are distinguished from each other by both their morphology and the appearance of their galls. The new genus is diagnosed and placed in the tribe Oligotrophini within the supertribe Lasiopteridi of the subfamily Cecidomyiinae.

KEY WORDS: Cecidomyiidae, *Trigonomyia ananas* sp. nov., *Trigonomyia cristata* sp. nov., *Trigonomyia tulipa* sp. nov., *Olearia ramulosa*, *Olearia axillaris*, South Australia.

Introduction

Three new gall midge species are described here that were found galling flowers of two species of the daisy-bush, *Olearia* Moench (Asteraceae). *Trigonomyia ananas* sp. nov. was found in Black Hill Conservation Park, near Adelaide, infesting the twiggy daisy-bush, *O. ramulosa* (Labill.) Benth. *Trigonomyia cristata* sp. nov. and *T. tulipa* sp. nov. were discovered at Beachport, in the Lower South-East of South Australia, both attacking the coastal daisy-bush, *O. axillaris* (D.C.) F. Muell. ex Benth.

Olearia includes some 75 species in Australia and 25 in New Zealand and New Guinea (Cooke 1986). *Olearia ramulosa* is an aromatic shrub, about 1.5 metres high, much-branched, with a woody stem and numerous, small, yellow-white flowers which occurs throughout Australia in mallee, woodland and coastal scrub (Cooke 1986). It is common in Black Hill Conservation Park where it often forms dense localised populations on poor stony soils. *Olearia axillaris* is a 2-3 metres high shrub, morphologically distinguished from *O. ramulosa* by larger leaves and minute ligules. *Olearia axillaris* forms a dense scrub on coastal sand dunes of moderate and temperate Australia (Cooke 1986) and is a dominant plant along the Beachport sea shore.

A new genus is proposed for the three new gall midge species. It is placed in the subfamily Cecidomyiinae and supertribe Lasiopteridi. It is compared to *Rhopalomyia* of the tribe Oligotrophini from which it

is morphologically distinguished by the male genitalia and the larval neck segment. The three new species differ from each other in morphology of the male gonostyli, the ovipositors, the pupal prothoracic spiracles, and the galls.

Material and Methods

Three distinct kinds of flower galls were sampled. One was collected from *O. ramulosa* in Black Hill Conservation Park near Adelaide (17.ix.1994) and two from *O. axillaris* on coastal sand dunes at Beachport (6.x.1994). The two types of galls collected from *O. axillaris* were kept in separate bags and all galls were processed in two ways according to the method previously described (Kolesik 1995). Microscope mounts of the type specimens were prepared by maceration in 20% KOH, followed by processing through distilled water, 70% and 99% ethanol, xylene and were mounted in Canada balsam for examination by phase-contrast and bright-field microscopy. Larvae, pupae and pupal skins were mounted dorso-ventrally. Adults were dissected into four (females) or five (males) pieces and their particular parts mounted separately: wing, head frontally, thorax laterally, female abdomen dorso-ventrally or laterally and male genitalia and abdomen dorso-ventrally. Measurements were made with an eyepiece graticule. Drawings were done with the aid of a camera lucida. The type series and other materials retained in 70% ethanol are deposited in the South Australian Museum, Adelaide [SAM], the Australian National Insect Collection, Canberra [ANIC] and the United States National Museum, Washington DC [USNM]. Adult terminology follows usage in Gagné (1981). Both larval and pupal terminology follows Gagné (1994).

* Department of Horticulture, Viticulture and Oenology University of Adelaide PMB 1 Glen Osmond S. Aust. 5064.

Genus *Trigonomyia* gen. nov.Type species: *Trigonomyia ananas**Adults*

Wings with R_3 joining C' at wing apex, R_4 absent, R_1 joining C' near wing mid-length, M_3 absent, Cu forked. Maxillary palpus with 3 segments, palpiger well developed. Eye facets rounded, eye bridge 2-4 facets medially. Antenna with variable number of flagellomeres, usually 16-18, first and second only weakly separated. Flagellomeres cylindrical with neck longer in male than in female; with long and stout setae in up to three whorls; circumilar loops short, forming sparse network, similar in both sexes. Empodia longer than claws, pulvilli stout, about half claw length. Claws simple, broadly curved. Abdomen: tergite I sclerotized in both sexes, with posterior setal row only, tergites II - VIII in male and II - VII in female sclerotized, with single posterior setal row interrupted mesally, pair of sparse setal fields laterally and one seta in both anterior corners, female tergite VIII not sclerotized, with triangular field of scattered setae at posterior end; sternites II - VIII in male and II - VII in female sclerotized, with dense, uninterrupted posterior band of setae, scattered setae anteriorly and isolated pair of setae on posterior end. Male genitalia: gonocoxites cylindrical, unlobed, setose and setulose; gonostylus situated caudally on gonocoxite, cylindrical, slightly tapering towards apex, with short apical tooth comprising one claw and several firm bristles, setose, setulose throughout; cerci bilobed, with several stout setae on each lobe, setulose; hypoproct bilobed, with one long seta on each lobe, setulose; parameres divided into two parts, basal lobe simple, asetose, setulose, apical lobe asetulose, bearing 5-6 parallel running lamellae, asetulose, bearing altogether 6-8 large, setose papillae; aedeagus robust, strongly sclerotized ventrally and apically, with apical end triangular. Ovipositor: protrusible; cerci fused into single, terminal lamella, triangular in dorso-ventral view, with numerous strong setae, setulose; hypoproct trapezoid in dorso-ventral view, short, bearing 2 setae posteriorly, setulose.

Pupa

Integument of abdominal segments covered by spiculae. Prothorax and abdominal segments I-VIII with spiracles. Antennal horns short, angular. Cephalic pair of papillae with strong, long setae. Frons with one pair of upper frontal weakly sclerotized depressions and one of 2 lower facial papillae on each side with short seta. Abdominal segments I-VII with 1 pair of ventral papillae, 2 pairs of pleural papillae and 3 pairs of dorsal papillae. Abdominal segments VIII and IX with 1 pair of ventral, 2 pairs of pleural papillae and 1 pair of dorsal papillae. All papillae setose.

Larva

Integument completely covered with dense spiculae.

Head: strongly sclerotized, posternolateral apodemes shorter than one fourth of head capsule length, antennae about three times longer than wide at base, conical. Neck segment with 1 pair of setose pleural papillae. Thoracic segments without spatula but with depression where spatula would normally appear, 1 pair of ventral papillae, 2 pairs of lateral papillae, 2 pairs of pleural papillae, 3 pairs of dorsal papillae. Abdominal segments I-VII with two sternal depressions, 1 pair of ventral papillae, 2 pairs of pleural papillae, 3 pairs of dorsal papillae. Abdominal segment VIII with 2 pairs of ventral papillae, 2 pairs of pleural papillae, 1 pair of dorsal papillae. Abdominal segment IX with 4 pairs of terminal papillae. All papillae setose except thoracic lateral ones. Setae long and clearly apparent on all papillae with exception of ventral papillae which are only slightly longer than integumental spiculae.

Etymology

Trigonomyia combines "trigōnion", Gk for triangle which refers to the shape of the apical end of aedeagus and "myia", Gk for fly, commonly used as suffix for genera of Cecidomyiidae.

Remarks

Trigonomyia belongs to the tribe Lasiopteridi because it has male parameres and an irregular number of antennal flagellomeres. The new genus belongs to the Oligotrophini and within that tribe to a group of genera that includes *Rhopalomyia*, and for which the tribal name Oligotrophini (in the strict sense, not including Dasineurini), is available. These genera share the following derived characters: reduction of the palpus to three or fewer segments, relatively short parameres that do not clasp the aedeagus along its full length, larvae each living in a separate cell in galls with pupation occurring inside the larval cell. Other, probably primitive characters shared by all members of *Rhopalomyia* and relatives are the completely setulose male gonostylus and the never divided female eighth abdominal tergite, even when the ovipositor is elongate (Gagné *et al.* in press). *Trigonomyia* differs from *Rhopalomyia* in several ways. In *Trigonomyia* the parameres are divided into two distinct lobes, the aedeagus is sclerotized apically and the larva has setose collar papillae. None of these characters has been noted in *Rhopalomyia* or related genera, although presumably separately derived, indistinct to distinct divisions can be found in the parameres in *Dasineura* (s.l.), *Lasioptera* and *Ledomyla* (Gagné 1994).

Trigonomyia ananas sp. nov.
(FIGS 1, 2, 5-8, 11-17, 19, 21, 22)

Holotype: ♂. Black Hill Conservation Park, South

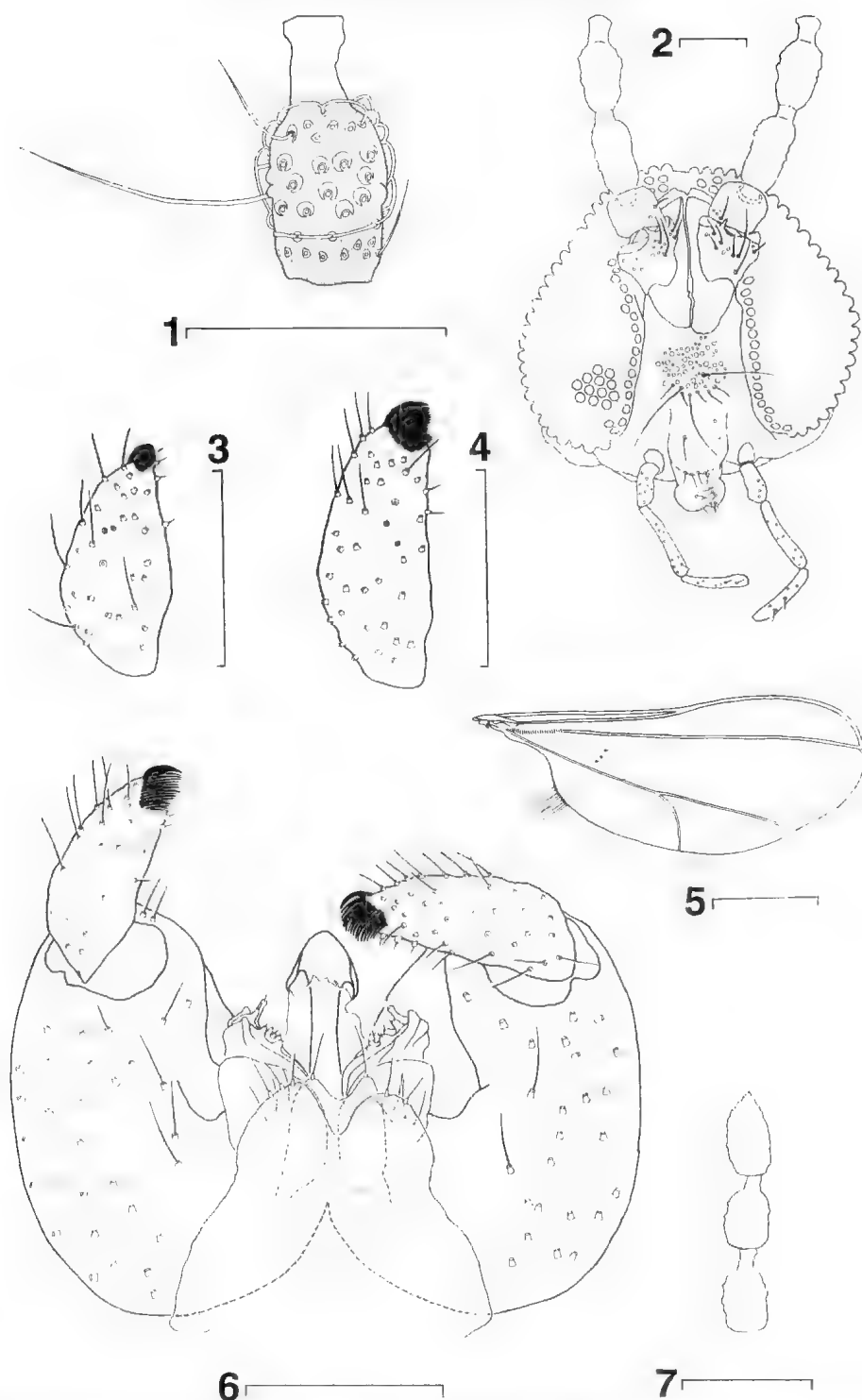


Fig. 1. Sixth flagellomere of male *Trigonomyia ananas* sp. nov. Fig. 2. Head of male *Trigonomyia ananas* sp. nov. in frontal view. Fig. 3. Gonostylus of male *Trigonomyia tulipa* sp. nov. in dorsal view. Fig. 4. Gonostylus of male *Trigonomyia cristata* sp. nov. in dorsal view. Fig. 5. Wing of male *Trigonomyia ananas* sp. nov. Fig. 6. Genitalia of male *Trigonomyia ananas* sp. nov. in dorsal view. Fig. 7. Last three flagellomeres of male *Trigonomyia ananas* sp. nov. Scale bars = 100 μ m 1-4, 6, 7; 1 mm 5.

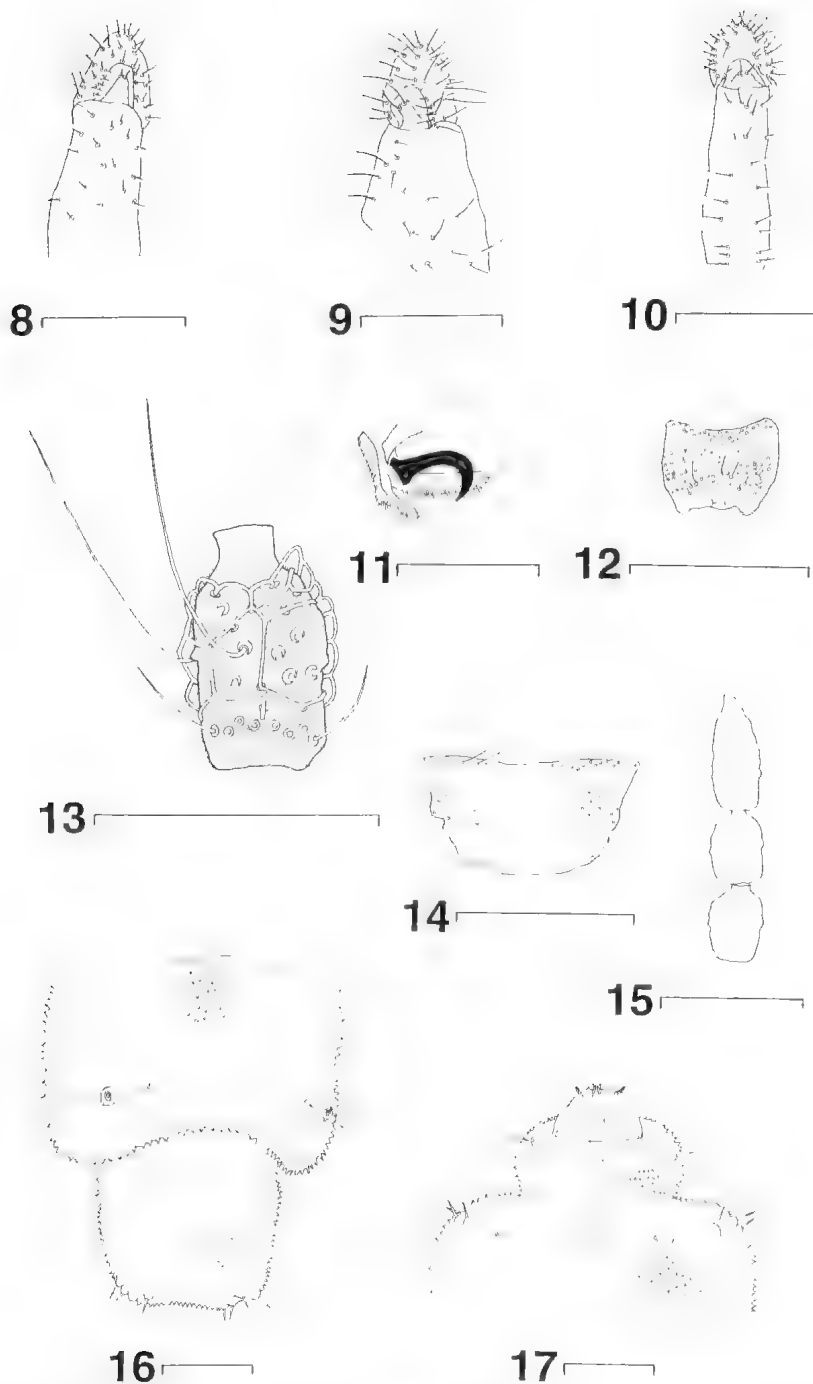


Fig. 8. End of ovipositor of female *Trigonomyia ananas* sp. nov. in ventral view. Fig. 9. End of ovipositor of female *Trigonomyia cristata* sp. nov. in ventral view. Fig. 10. End of ovipositor of female *Trigonomyia tulipa* sp. nov. in ventral view. Fig. 11. End of last tarsomere with claw, empodium and pulvillus of female *Trigonomyia ananas* sp. nov. in lateral view. Fig. 12. Sixth sternite of female *Trigonomyia ananas* sp. nov. Fig. 13. Sixth flagellomere of female *Trigonomyia ananas* sp. nov. Fig. 14. Fifth tergite of female *Trigonomyia ananas* sp. nov. Fig. 15. Last three flagellomeres of female *Trigonomyia ananas* sp. nov. Fig. 16. Last two abdominal segments of larva of *Trigonomyia ananas* sp. nov. in dorsal view. Fig. 17. Head and first two thoracic segments of larva of *Trigonomyia ananas* sp. nov. in ventral view. Scale bars = 100 μ m 8-10, 13, 15-17; 50 μ m 11; 500 μ m 12, 14.

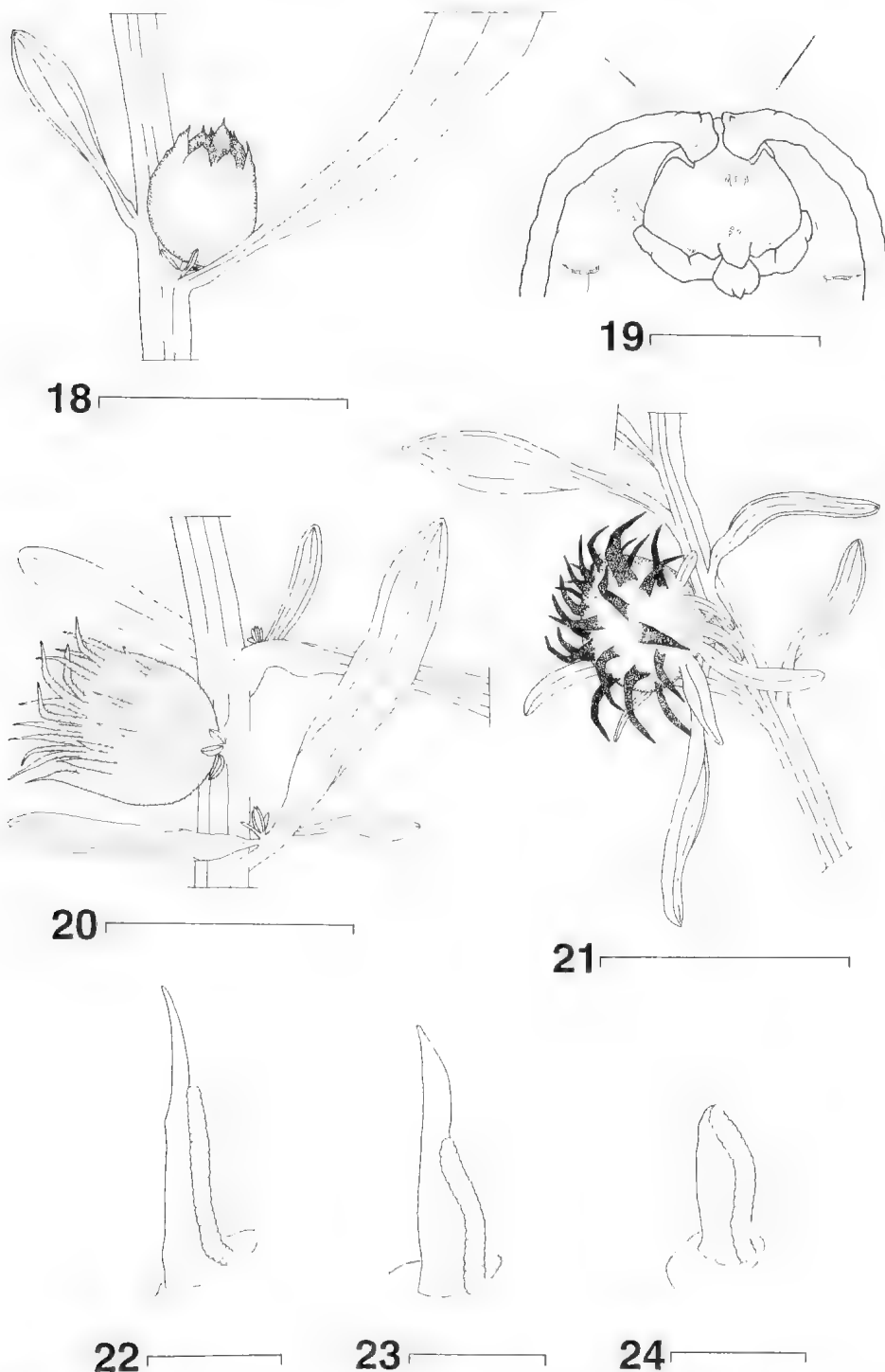


Fig. 18. *Trigonomyia tulipa* sp. nov. - flower gall on *Olearia axillaris*. Fig. 19. Frons of pupa of *Trigonomyia ananas* sp. nov. Fig. 20. *Trigonomyia cristata* sp. nov. - flower gall on *Olearia axillaris*. Fig. 21. *Trigonomyia ananas* sp. nov. - flower gall on *Olearia ramulosa*. Fig. 22. Prothoracic spiracle of pupa of *Trigonomyia ananas* sp. nov. Fig. 23. Prothoracic spiracle of pupa of *Trigonomyia cristata* sp. nov. Fig. 24. Prothoracic spiracle of pupa of *Trigonomyia tulipa* sp. nov. Scale bars = 10 mm 18, 20, 21; 500 μm 19; 50 μm 22-24.

Australia [34°54'S, 138°44'E], 20.ix.1994, P. Kolesik, reared from flower gall of *Olearia ramulosa* (Labill.) Benth., sampled 17.ix.1994, 121294 [SAM].

Allotype: ♀, same data, 121295 [SAM].

Paratypes (all sampled with holotype): 1♂ [SAM], 1♂ [ANIC], 2♀♀ [SAM], 2♀♀ [ANIC], 2 pupal skins [SAM], 2 pupal skins [ANIC], emerged 20.ix-8.x.1994; 2 larvae [SAM], 1 larva [ANIC].

Other material (all sampled with holotype): 3♀♀ [USNM], 4 pupae [SAM], 3 pupae [USNM], emerged 5-8.x.1994; 4 larvae [SAM], 3 larvae [USNM].

Description

Male (Figs 1-2, 5-7)

Colour: antennae grey, head black, thorax brown, abdomen with sclerotized parts black and non-sclerotized red (same in other two species). Wing length 3.1 mm (2.9-3.2), width 1.1 mm (1.1-1.2). Antenna total length 1.5 mm (1.5-1.6). Gonostylus 124 µm (121-127) long, 45 µm (43-49) wide, length of apical claw of gonostylus 17 µm (16-18).

Female (Figs 8, 11-15)

Colour as in male. Wing length 3.0 mm (2.9-3.1), width 1.1 mm (1.0-1.1). Antenna total length 1.4 mm (1.3-1.5). Cercus 65 µm (60-68) long, 57 µm (57-58) wide, setae 5-28 µm long.

Larva (Figs 16, 17)

Colour red (same in other two species). Total length 3.0 mm (2.7-3.6). Head capsule: length 57 µm (50-62), width 95 µm (92-101), posterolateral apodemes 13 µm (11-16) long; antenna 17 µm long, 6 µm wide at base. Length of setae: 2-3 µm in ventral papillae of thorax and abdomen I-VII, 10-20 µm in remaining papillae. Integumental spiculae 1-2 µm long.

Pupa (Figs 19, 22)

Colour: non-sclerotized parts of abdomen red, remaining parts dark-brown (same in other two species). Total length 3.3 mm (2.3-3.9). Length of setae on cephalic papillae 361 µm (354-369). Prothoracic spiracle 98 µm (93-103) long, trachea 70 µm (60-75) long.

Gall (Fig. 21)

Flower bud transformed into spherical, thin walled, monothalamous rosette, 4-6 mm in diameter. When fresh, gall wall green, malformed ligules violet. One larva inside each gall. Pupation takes place within gall. In the area surveyed, most shrubs were infested with up to 200 galls per plant.

Etymology

The word "ananas", a noun in apposition, is the generic name of pineapple and refers to the resemblance of the gall to a pineapple.

Trigonomyia cristata sp. nov. (FIGS 4, 9, 20, 23)

Holotype: ♂, Beachport, South Australia [37°29'S, 140°00'E], 8.x.1994, P. Kolesik, reared from flower gall of *Olearia axillaris* (DC.) F. Muell. ex Benth., sampled 6.x.1994, 121296 [SAM].

Allotype: ♀, same data, 121297 [SAM].

Paratypes (all sampled with holotype): 1♂ [SAM], 1♂ [ANIC], 2♀♀ [SAM], 2♀♀ [ANIC], 3 pupal skins [SAM], 2 pupal skins [ANIC], emerged 8-19.x.1994; 1 larva [SAM].

Other material (all sampled with holotype): 2♀♀ [USNM], 3 pupae [USNM], emerged 8-19.x.1994; 1 larva [SAM], 3 larvae [USNM].

Description

Male (Fig. 4)

Wing length 3.4 mm (3.4-3.5), width 1.3 mm (1.3-1.4). Antenna total length 1.7 mm (1.7-1.8). Gonostylus 150 µm (145-157) long, 55 µm (50-58) wide, length of apical claw of gonostylus 20 µm (19-22).

Female (Fig. 9)

Wing length 3.2 mm (3.1-3.4), width 1.2 mm (1.1-1.2). Antenna total length 1.4 mm (1.3-1.6). Cercus 60 µm (55-63) long, 50 µm (47-52) wide, setae 17-45 µm long.

Larva

Total length 3.0 mm (2.4-3.4). Other measurements within the range of *T. ananas*.

Pupa (Fig. 23)

Total length 3.7 mm (3.1-4.2). Length of setae on cephalic papillae 386 µm (361-427). Prothoracic spiracle 96 µm (86-107) long, trachea 57 µm (51-62) long.

Gall (Fig. 20)

Flower bud transformed into monothalamous, thick-walled gall, 4-8 mm long, 3-6 mm wide, covered entirely with numerous, densely-haired, malformed ligules growing from proximal end. When fresh, both ligules and gall wall green in colour. One larva in each gall. Pupation takes place within gall. At Beachport, *T. cristata* was found with *T. tulipa* on the same shrubs with up to 20 galls of each species per plant.

Etymology

The word "cristata" is L., for tufted, referring to the general appearance of the gall.

Trigonomyia tulipa sp. nov. (FIGS 3, 10, 18, 24)

Holotype: ♂, Beachport, South Australia [37°29'S, 140°00'E], 9.x.1994, P. Kolesik, reared from flower gall of *Olearia axillaris* (DC.) F. Muell. ex Benth., sampled 6.x.1994, 121298 [SAM].

Allotype: ♀, same data, I21299 [SAM].

Paratypes (all sampled with holotype): 2 ♂♂ [SAM], 1 ♂ [ANIC], 2 ♀♀ [SAM], 2 ♀♀ [ANIC], 3 pupal skins [SAM], 2 pupal skins [ANIC], emerged 9-17.x.1994; 2 pupae [SAM], 2 pupae [ANIC]; 3 larvae [SAM], 2 larvae [ANIC].

Other material (all sampled with holotype): 1 ♀ [USNM], 4 pupal skins [SAM], 3 pupal skins [USNM], 1 pupa [SAM], 3 pupae [USNM], emerged 9-17.x.1994.

Description

Male (Fig. 3)

Wing length 3.3 mm (3.3-3.4), width 1.3 mm (1.2-1.3). Antenna total length 1.7 mm (1.6-1.8). Gonostylus 121 µm (119-126) long, 50 µm (45-53) wide, length of apical claw of gonostylus 13 µm (12-14).

Female (Fig. 10)

Wing length 2.7 mm (2.4-3.2), width 1.0 mm (0.7-1.1). Antenna total length 1.3 mm (1.1-1.5). Cercus 56 µm (52-61) long, 50 µm (43-55) wide, setae 6-20 µm long.

Larva

Total length of the only specimen 2.7 mm. Other measurements within the range of *T. ananas*.

Pupa (Fig. 24)

Total length 3.2 mm (2.8-3.4). Length of setae on cephalic papillae 395 µm (364-455). Prothoracic spiracle 51 µm (48-53) long, trachea same length.

Gall (Fig. 18)

Flower bud transformed into smooth, monothalamous, thin-walled gall, 4-6 mm in length, 3-4 mm in width, with tips of malformed ligules sticking out at distal end. When fresh, colour purple. One larva inside each gall. Pupation takes place within gall.

Etymology

The word "tulipa", a noun in apposition, is the generic name of tulip and refers to the resemblance of the gall to a tulip.

Key to species of *Trigonomyia*

1. Trachea reaching end of thoracic spiracle in pupa (Fig. 24). Apical claw of gonostylus diminutive, 1/4 of gonostylus width (Fig. 3). From untufted galls of *Olearia axillaris* (Fig. 18) *T. tulipa*
Trachea never reaching end of thoracic spiracle in pupa (Figs 22, 23). Apical claw of gonostylus large, more than 1/3 of gonostylus width (Figs 4, 6). From tufted galls of *Olearia* spp. (Figs 20, 21) 2
2. Longest setae on female cercus shorter than 2/3 of cercus width (Fig. 8). From pineapple-shaped, glabrous, thin-walled galls of *Olearia ramulosa* (Fig. 21). *T. ananas*
Longest setae on female cercus longer than 2/3 of cercus width (Fig. 9). From hairy, thick-walled galls of *Olearia axillaris* (Fig. 20) *T. cristata*

Acknowledgments

The Ministry of Environment and Planning South Australia kindly gave permission to collect in the Black Hill Conservation Park. Abid A. Munir State Herbarium of South Australia Adelaide courteously identified the host plant species. I am grateful to John D. Gray Department of Horticulture, Viticulture and Oenology University of Adelaide and Raymond J. Gagné Systematic Entomology Laboratory USDA Washington DC USA for their careful review of the manuscript.

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FIRST FOSSIL RECORD OF THE HYLID FROG LITORIA RANIFORMIS (KEFERSTEIN)

BRIEF COMMUNICATION

Summary

The Australian hylid frog *Litoria raniformis* (Keferstein) is a member of a group of similar species known as the *L. aurea* complex¹, and is one of the largest species in Australia² (snout to vent length up to 104 mm). The geographic range of the species extends from South Australia through Victoria, the ACT and Tasmania to eastern New South Wales³. The species also has been introduced into New Zealand and has become established there⁴.

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The Australian hylid frog *Litoria raniformis* (Keferstein) is a member of a group of similar species known as the *L. aurea* complex¹, and is one of the largest species in Australia² (snout to vent length up to 104 mm). The geographic range of the species extends from South Australia through Victoria, the ACT and Tasmania to eastern New South Wales³. The species also has been introduced into New Zealand and has become established there⁴.

It has been a source of surprise that such a large species seemingly is absent from Holocene and Pleistocene sites in south-eastern Australia where other extant sympatric species have been found in abundance⁵.

Here we report the first specimens of *L. raniformis* from the fossil record. The ilial descriptive terminology follows Tyler⁶.

The largest and most complete specimen is a left ilium, located in March 1995, from material extracted at the 'East Low' site at Henschke's Cave, SA (Lat. 36°58'-06, Long. 140°45'-58). The specimen has been deposited in the palaeontological collection at the South Australian Museum and registered as SAM P35305. The specimen has a length of 28.0 mm which is less than the known maximum ilial length of the species (35 mm)⁵. However, it is larger than other Pleistocene frog ilia known from the area and its identification has been confirmed by comparison with extant specimens, an example of which is shown in Fig. 1. SAM P35305 is fragile and partly encrusted with matrix, hence the extant specimen is more useful for identification purposes. A line drawing of the sectional form of the ilium of this species has been published elsewhere⁷.

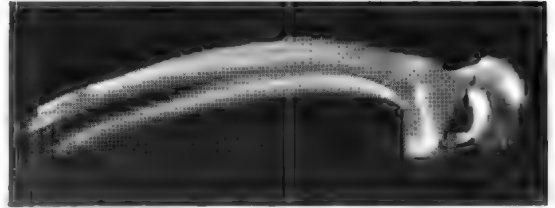


Fig. 1 Pelvis of extant *Litoria raniformis* from left, lateral aspect. Length of ilium = 31 mm. (Photo: P. Kempster)

Salient features are the poorly developed dorsal prominence and dorsal protuberance, only slight elevation of the dorsal acetabular expansion, a narrow and gently curved pre-acetabular zone and a shallow longitudinal indentation upon the lateral surface of the ilial shaft.

We refer two other partial ilia from Henschke's Cave to this species: SAM P32249 and P35306.

The age of the deposit has been estimated to be from 35,000⁸ to 100,000⁹ years. These papers, provide information on the depositional nature and stratigraphic sequence of the material.

We thank the Australian Research Council for funding Michael Tyler's investigations of fossil frogs and Peter Kempster for Figure 1.

¹Tyler, M. J. & Davies, M. (1978) Aust. J. Zool. Suppl. 63, 1-47.

²Tyler, M. J. (1978) 'Amphibians of South Australia' (Handbooks Committee, Adelaide).

³Tyler, M. J. (1994) 'Australian frogs. A natural history' (Reed, Melbourne).

⁴McCann, C. (1961) Tuatara, 8(3), 107-120.

⁵Tyler, M. J. (1977) Trans. R. Soc. S. Aust. 101(3), 85-89

⁶Tyler, M. J. (1976) *Ibid.* 101(1) 3-14.

⁷Tyler, M. J. (1986) Alcheringa 10, 401-402.

⁸Pledge, N. S. (1981) *Ibid.* 105(1), 41-47.

⁹Barrie, D. J. (1990) Mem. Qld Mus. 28(1), 139-151.

THE TADPOLE OF LITORIA REVELATA INGRAM, CORBEN AND HOSMER, 1982 (ANURA: HYLIDAE)

BRIEF COMMUNICATION

Summary

Litoria revelata Ingram, Corben & Hosmer, 1982 is a medium sized tree-frog that has three disjunct populations; in northern Queensland (Atherton Tableland and the Bellenden-Ker Range), mid-eastern Queensland (Eungella Plateau) and the extreme corner of south eastern Queensland and northern NSW, Australia¹. Herein we present a description of the tadpole of *L. revelata* from the rainforest in the Eungella region in mid-eastern Queensland. Habitat and life history notes are presented to assist identification in the field but these are intended as a guide only and tadpoles could be found in different habitats and months from those given.

BRIEF COMMUNICATION

THE TADPOLE OF *LITORIA REVELATA* INGRAM, CORBEN AND HOSMER, 1982 (ANURA: HYLIDAE).

Litoria revelata Ingram, Corben & Hosmer, 1982 is a medium sized tree-frog that has three disjunct populations; in northern Queensland (Atherton Tableland and the Bellenden-Ker Range), mid-eastern Queensland (Eungella Plateau) and the extreme corner of south eastern Queensland and northern NSW, Australia¹. Herein we present a description of the tadpole of *L. revelata* from the rainforest in the Eungella region in mid-eastern Queensland. Habitat and life history notes are presented to assist identification in the field but these are intended as a guide only and tadpoles could be found in different habitats and months from those given.

Tadpoles were collected in November and December of 1993 at several stream sites near the Eungella township, approximately 70 km west of Mackay, central Queensland, Australia (Table 1). A sample of larvae was preserved in 10% formalin and others were reared to metamorphosis for identification. Terminology follows Altig² and Hero³; developmental stages follow Gosner⁴. Measurements were taken using vernier callipers. Height of the caudal muscles and fins was measured at mid-length of the tail. The drawings

depict melanic patterns that persist in preserved specimens (10% formalin). The colour descriptions should be treated with caution as tadpole colour is often a function of water clarity⁵. Drawings were made of two representative specimens (Figs 1 and 2) placed in the Queensland Museum, Brisbane (QM J 59239 and J 59240). The labial tooth-row formula (LTRF) is based on observations of all specimens collected at Gosner⁴ stages 25 through 45 (QM J 59241 and J 59242; Table 1).

Description: Eyes lateral; eye diameter 14.5% of the body length for stage 35 tadpoles and 14.7% for stage 40 tadpoles. Nares dorsal, nearer to tip of snout than to anterior edge of eye; narial margin without rim; spiracle paragyrid (Fig. 2 C) located well below the horizontal longitudinal axis but not on the midline so neither sinistral nor medioventral is entirely applicable⁶), unpigmented, opening directed posteriorly.

Vent tube dextral, attached to fin. Oral disc ventral. Single row of large blunt, heavily pigmented marginal papillae with wide anterior gap. Submarginal papillae present. Two rows of labial teeth on anterior labium with median gap in second row; three rows of labial teeth on posterior labium with median gap in first row: LTRF 2(2)/3 (1). Dorsal fin terminates at tail-body junction. Both dorsal and ventral fins higher than caudal musculature at midlength of tail. Tail-tip tapers uniformly to narrow point. These morphological features conform to the general characteristics for tadpoles of the genus *Litoria*.

In life, body opaque, appearing "bluish" and heavily pigmented with lighter pigmentation around eyes; darkly pigmented supracranial patch (especially in larger tadpoles) extending posteriorly over spinal cord (Fig. 2B); distinct broad

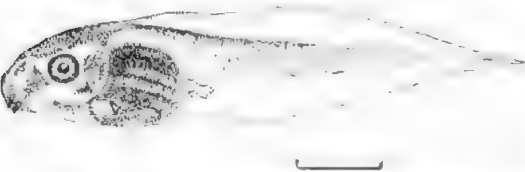


Fig. 1. Tadpole of *Litoria revelata* (QM J 59240; Gosner stage 35; TL 31.5 mm). Scale bar = 5 mm.

TABLE 1. Dates, Localities and Museum Numbers for additional specimens examined in this study: Mt William (upper Cattle Cr.; Map 8655, MGR 666740), Mt David (upper Cattle Cr.; Map 8655, MGR 678744).

Date	Place Collected	Gosner Stage (No.)	Body Length (mean)	Total Length (mean)	Qd Mus. No.
27.xi.93	Cattle Cr. Mt William	25	4.6-8.1	11.2-18.3	J 59242
		(7)	(6.6)	(15.3)	
		26	9.5	23.2	
		27	10.6	26.7	
		28	8.4	21.5	
		29	11.3	27.4	
		31	12.0	29.8	
		33	11.7	30.6	
		36	12.4	31.2	
		37	13.3	33.3	
		42	11.1-12.0	29.6-35.1	
		(2)	(11.5)	(32.3)	
		43	10.5	-	
		44	11.4-13.4	-	
		(5)	(12.3)	-	
29.xi.93	Cattle Cr. Mt David	25	8.8-10.6	21.1-25.2	J 59241
		(3)	(9.7)	(23.1)	
		27	11.4-11.9	26.1-27.6	
		(2)	(11.6)	(26.8)	
		31	12.0	33.0	
		37	14.6	43.1	
		41	14.4	40.8	

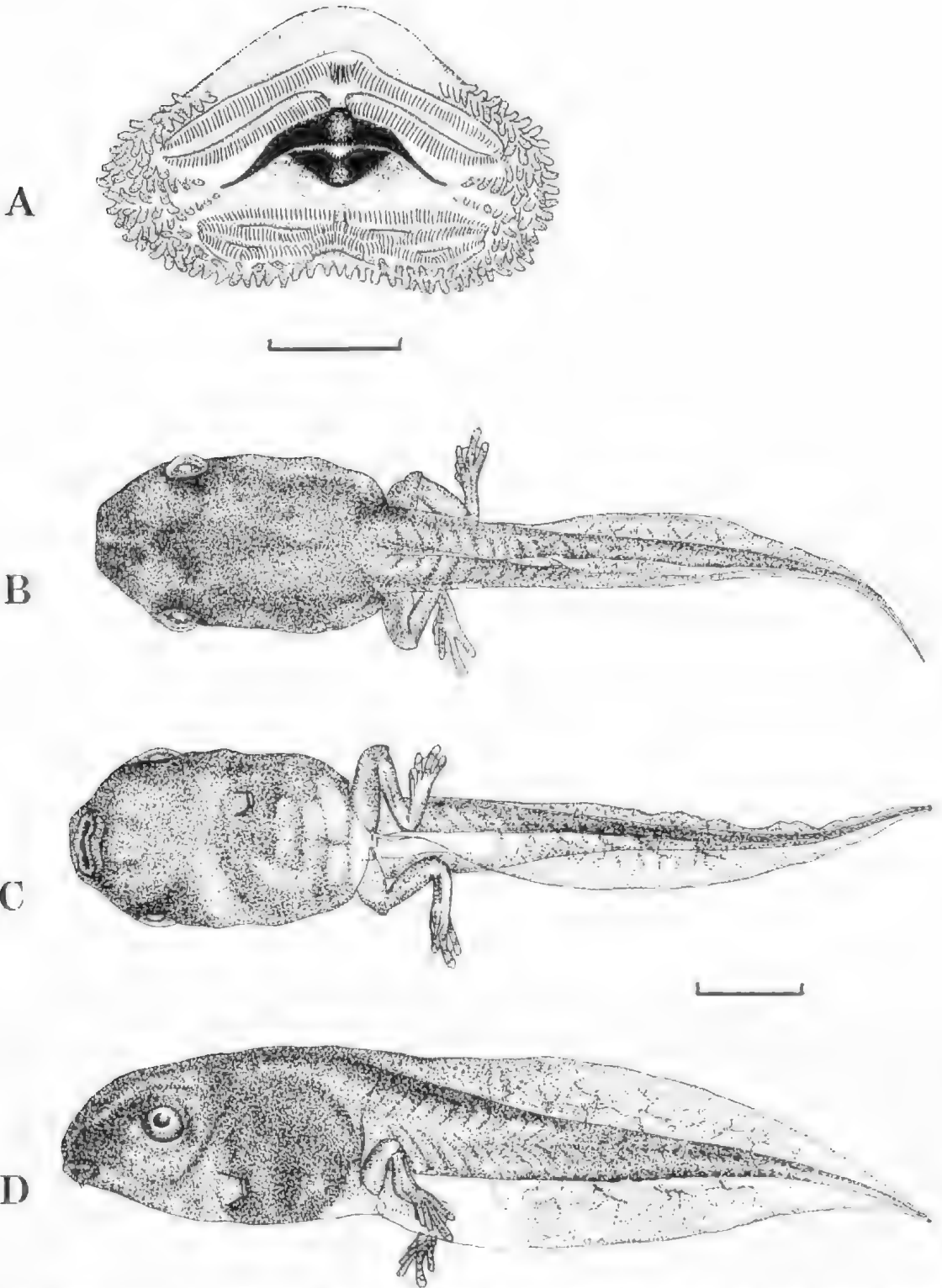


Fig. 2. Tadpole of *Litoriu revelata* (QM J 59239; Gosner Stage 40; TL 40.8 mm) A. Oral disc. B. Dorsal view. C. Ventral view. D. Dorso-lateral view. Scale bars = 1 mm (A), 5 mm (B,C,D).

vertical subdermal lines on dorsal side of each naris. Horizontal band or patch from snout to eye (Fig. 2D). Pigmentation often lighter during earlier stages (Fig. 1) than at later stages (Fig. 2B-D). In ventral view intestinal mass visible, intestinal coils partially visible and obscured by heavy pigmentation; branchial region semi-transparent. Tail musculature an even shade of grey/brown with additional melanophores concentrated dorsally (Fig. 2D). Dorsal and ventral fins transparent, with even stippling of dark melanophores, often outlining venation.

A tadpole at Stage 35 (Fig. 1) had the following measurements (mm): total length 31.5, body length 11.7, body width 6.5, body height 6.0, tail height 7.2, interorbital distance 5.6, internarial distance 2.1, eye-naris distance 2.0. A tadpole at Stage 40 (Fig. 2) had the following measurements (mm): total length 40.8, body length 14.3, body width 8.2, body height 7.3, tail height 8.3, interorbital distance 6.2, internarial distance 2.0, eye-naris distance 2.6. Tadpoles vary in total length from 11.2 mm at Stage 25 to 43.1 mm at Stage 37 (Table 1).

Diagnosis. At the sites studied, live tadpoles of *L. revelata* can easily be confused with *L. chloris* as both species occur in mid-water sections of isolated streamside pools and they have similar body shape and oral disc formula. Live tadpoles of *L. revelata* have a bluish sheen covering the intestinal mass and the intestinal coil is partially visible (Fig. 2C). In contrast, *L. chloris* has a golden sheen covering the intestinal mass, the intestinal coils are visible mid-ventrally and golden chromatophores cover the heart.

In preservation, tadpoles of *L. revelata* have pigmentation covering the intestinal mass making the intestinal coils only partially visible. In contrast, *L. chloris* has a transparent ventral surface and the intestinal coils are clearly visible. The position of the spiracle, paragyrid in *L. revelata* and sinistral in *L. chloris* and the dark pigmentation on the oral papillae of *L. revelata* (with only few scattered pigments on the oral papillae of *L. chloris*) also distinguish these two species. Interestingly, we only know of one other *Litoria* sp. in Australia with a paragyrid spiracle (*L. rubella*, unpubl.). Tadpoles of *L. revelata* were found in sympatry with tadpoles of *L. chloris* and *Taudactylus liemi*. Adult frogs of *T. eungellensis* and *Mixophyes fasciolatus* were also observed in adjacent streams.

Habitat: Tadpoles of *L. revelata* were found in isolated bedrock pools adjacent to fast-flowing rocky streams surrounded by pristine rainforest. Each pool contained leaf litter and algae and was between 1.5 and 2.5 m from the stream. No fish were observed or captured by dip netting the pools. Water temperatures were noticeably higher in the pools than in the adjacent stream (Table 2). Pool dimensions in November were 100 cm x 50 cm x 10 cm deep for pool 1

TABLE 2. Water temperatures ($^{\circ}$ C) of pools and the adjacent stream at two sites.

Site	Date	Pool 1	Pool 2	Adjacent Stream
Cattle Cr Mt William	18.ix.94	14.9	16.0	14.2
	16.x.94	16.8	17.2	15.2
	13.xi.94	19.7	20.5	17.9
	11.xii.94	20.0	19.6	18.0
Cattle Cr. Mt David	19.ix.94	17.5	16.0	13.5
	17.x.94	21.3	-	15.0
	14.xi.94	20.0	-	17.0
	12.xii.94	22.5	22.8	17.9

and 200 cm x 100 cm x 25 cm deep for pool 2. Tadpoles were generally observed in the midwater and surface water rather than the benthic layer of the water column and were frequently observed rising to the surface to gulp air.

This research was partially funded by the Australian Nature Conservation Agency, the Queensland Department of Environment and Heritage, the Wet Tropics Management Authority and the Cooperative Research Centre for Tropical Rainforest Ecology and Management. Research was carried out under a Qld Dept of Environment and Heritage "Permit to Take" no. 100177. We wish to thank Michael Cunningham for his contribution to this paper and Julie Martin who prepared the illustrations and the volunteers who assisted in the J.C.U. Eungella Frog Search in November/December, 1993. Ross Alford provided logistical support at J.C.U. and Marion Anstis gave valuable comments on a draft.

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OBITUARY

NELLY HOOPER LUDBROOK, MBE, MA, PhD, DIC, FGS.

14.vi.1907 – 9.v.1995.

President of the Royal Society of South Australia Inc. 1961

Summary

An “obituary” is usually an account of a deceased person, but Nell Ludbrook deserves more than just that. She really meant something to us so you must excuse me if I depart from the kinds of ledger account statements that often follow the death of those people who leave a significant mark on our community.

I first came across the name N. H. Ludbrook when I was a student at the University of Adelaide in the late 1960s. While I was searching through the stacks in the Barr Smith Library on some aspect of the evolution of interior deserts, her name appeared a number of times in a paper dealing with geomorphology. The more I searched related papers the more her name recurred. I must confess that, then, I didn’t know whether N. H. Ludbrook was male or female. All I knew was that the name was referred to in an array of papers dealing with stratigraphy, geological evolution, palaeontology, palaeoclimate, ancient glaciations and the list went on. And it didn’t seem to matter what part of the Phanerozoic either. I admit I thought that a person touching so many aspects of geoscience had to be of great physical and scientific stature. It was not until twenty odd years later when I actually met her that I found I was wrong on one count but I was certainly not disappointed. What a marvellous person and an extra-ordinary scientist I found her to be.



NELLY HOOPER LUDBROOK
MBE, MA, PhD, DIC, FGS.

At her office at the Department of Mines and Energy, Coe Library, Glenside, 1985. MESA photo no. 34475

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Nell (never Nelly) was born Nelly Hooper Woods at Yorketown, Yorke Peninsula on 14 June 1907, and educated at Mount Barker High School in the Adelaide Hills. During her undergraduate studies at The University of Adelaide she became fascinated with Late Tertiary Mollusca in the St Vincent Basin, a course of study not easy at that time because palaeontology was not offered by the university. This fascination broadened to the whole Cainozoic and continued through her long career. Nell graduated as BA (1928) and MA (1930), and was awarded the Tate Medal of the University of Adelaide for a research paper on molluscs obtained from an Adelaide Plains borehole. Even during her period of teaching at Mount Barker High School, she still found time to extend her knowledge of Mollusca.

Following her marriage in 1935, she and her husband, Wallis Vero Ludbrook, moved to Canberra where, undaunted, she continued her interest in Caino-

zoic Mollusca. It was fortunate at this time that the Commonwealth Palaeontologist function was moved from Melbourne to Canberra, undoubtedly facilitating her continuing interest in palaeontology. While in Canberra, from 1942 to 1949, Nell worked as Assistant Geologist in the Commonwealth Bureau of Mineral Resources dealing with statistics of strategic minerals.

In 1950 she travelled to London. Here at Imperial College and as a visiting scientist at the British Museum (Natural History) she continued to extend her palaeontological studies. Nell was awarded her PhD in geology (1952) from the University of London and the DIC in palaeontology for research on Pliocene Mollusca from the St Vincent Basin. Out of this research developed an authoritative chapter on fossil scaphopods in the first edition of the "Treatise of Invertebrate Paleontology" (1960).



Sampling Early Cretaceous Eromanga basin sediments near Marree, 1963. Photograph by R. G. Forbes. MESA photo no. 20035.

Following the death of her husband and on returning to Australia, Nell gained the position of Technical Information Officer with the South Australian Department of Mines in 1952. At this time palaeontology was seen to have little economic value - something more esoteric than having any practical application. It was no mean feat, therefore, that Nell, having been charged with the added responsibility of demonstrating the application of micropalaeontology in stratigraphy, succeeded way beyond expectations in this role. She won the enormous respect of colleagues around her and established biostratigraphy as an important function of the Department, a role that continues today.

During the heady days of early petroleum exploration in the Cooper Basin, Nell was the key scientist in determining the age and stratigraphy of samples from deep wells drilled into unknown strata. Even the then Premier of South Australia, Thomas Playford, waited with great interest for Nell's conclusions. Actually Nell admitted to me on one occasion that she did not really know what the age of some rock samples was, so she took a "stab". As it turned out, later work, employing far more sophisticated methods, showed her determinations to be correct - such was the great range of her knowledge.

In 1957 Nell was appointed Palaeontologist with the Department of Mines, and later, Senior Palaeontologist, in which capacity she continued biostratigraphic research until her "retirement" in 1967. During this time she developed an expertise in foraminiferal biostratigraphy, essential to unravelling the stratigraphy of largely buried strata in sedimentary basins throughout the State and aiding in the search for groundwater and petroleum. She travelled into remote areas of the Eucla and Eromanga Basins with mapping and drilling parties to undertake fossil collecting and stratigraphic investigations, often camping out in the open. Nell always insisted on seeing the field relationships of the sediments and faunas she worked on. It was through her field activities that biostratigraphy became firmly recognised as an integral part of geological mapping by the Department of Mines. This work culminated in the publication of two important monographs on the Murray Basin (1961) and the Eromanga Basin (1966), still very much referred to today as are the stratigraphic units she defined during the course of her studies.

"Retirement" really meant the continuation of her love of geology and especially for fossil Mollusca. She worked as a consultant in palaeontology to the Department of Mines and Energy until 1993, at which



N. H. Ludbrook and J. Spence examining Cainozoic sediments at North West Bend, along the River Murray. Photograph by A. R. Crawford. MESA photo no. T002001.

time she had reached the age of 86. In addition to the publication of a number of research papers during this time she wrote the highly successful "Guide to the Geology and Mineral Resources of South Australia" (1980) and later the "Handbook of Quaternary Molluscs of South Australia" (1985). As a demonstration of the great respect and admiration that her colleagues from all over the world had for her, a special honour volume of papers dealing with stratigraphy and palaeontology was published by the Department of Mines and Energy in 1985. Until only a short time before her death in 1995 Nell was still researching a large volume on Tertiary Mollusca.

Although the vast number of her publications (over 70 scientific papers and monographs) and Government reports was known to me, I only became aware of the full extent of her extraordinary energies whilst I was researching material for the 1995 Volume 2 of the "Geology of South Australia". During the course of rummaging through filing cabinets in the Biostratigraphy Branch containing countless numbers of her Report Books I came across a huge number of unpublished letters and personal communications to geologists in companies, academia and government carefully outlining the results of work undertaken for them, each almost of quality to be published notes in their own right. We are now the custodians of Nell's journals, books and notebooks, donated by her in 1994 and now housed in the N. H. Ludbrook Memorial Library at Mines and Energy South Australia.

Nell's interest in geology and the influence she had on the science (and related sciences for that matter) extended far beyond the workplace. She was very active as a member and office holder in the Geological Society of Australia from its inception. She was the

founding Secretary of the South Australian Division (1953-56) and Federal Secretary (1956-59), and a Member of the Stratigraphic Nomenclature Committee, in the early days of its operation. Nell was a driving force in the preservation of key geological sites and in the promotion of geological monuments. Nell was elected Federal President of the Geological Society in 1968 and Honorary Member in 1976 - such was the high respect that the geological community held for her.

Her great energies extended into the affairs of the Royal Society of South Australia. She was elected President in 1961-62, awarded the Sir Joseph Verco Medal in 1963, the highest honour from the Society, and was Editor of the Handbooks of the Flora and Fauna of South Australia from 1967 to 1980. Nell became an Honorary Associate of the South Australian Museum in 1981. In recognition of her service to science, in 1981 Nell Ludbrook was made Member of the Most Excellent Order of the British Empire.

During her great devotion to research in palaeontology and stratigraphy and her commitment to the affairs of scientific societies Nell still found time to guide and advise colleagues in many aspects of geoscience. She travelled widely throughout the world pursuing her love of geology - into many places where European women were rarely seen. Nell had the rare gift of being able to devote herself to this pursuit and yet still maintain an enormous interest in the cultural and musical life of Adelaide and the world at large. She loved entertaining at her home at Toorak Gardens - many an overseas visitor was delighted with her hospitality.

It was an honour and a pleasure for all of us to have known Nell Ludbrook.

NBVILLE F. ALLEY

OBITUARY

STANLEY JOE EDMONDS, BA, BSc, MSc, PhD, Dip Ed.

13.ii.1909 – 16.vii.1995.

President of the Royal Society of South Australia Inc. 1965

Summary

Stan Edmonds died quietly in his sleep on 16 July 1995 aged 86. He is sadly missed by his many friends from all walks of life who miss his sense of humour, joie de vivre and scholarship.

His working life fell roughly into three periods each about twenty years' duration. He was a school teacher at Adelaide High School from 1931 to 1952, he then taught and conducted research in the Zoology Department of the University of Adelaide from 1952 to 1974 and finally, as an Honorary Associate at the South Australian Museum, he continued his research from 1972 to 1995.



STANLEY JOE EDMONDS
BA, BSc, MSc, PhD, Dip Ed.
Photograph courtesy of the SA Museum

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Stanley Joe Edmonds was born in Adelaide (South Australia) on 13 February, 1909. He attended the Thebarton Primary School from 1915-1922 and the Woodville District High School from 1923-1925, obtaining his Intermediate Certificate in 1924 and his Leaving Certificate the following year. In 1926 he joined the Lands and Survey Department of the South Australian Public Service with the intention of becoming a surveyor. During this time he studied science part-time as a private student at the University of Adelaide doing Mathematics I during the day and Chemistry I and Physics I at night.

In 1927 he joined the Education Department and entered the Adelaide Teachers College. He graduated in 1929 with a BSc majoring in Inorganic and Organic Chemistry, and began his teaching career in 1930, teaching for six months at Woodville High School.

In 1931 he began his impressive twenty-year association with Adelaide High School, ultimately becoming a Special Senior Master in Chemistry and General Science and teaching Leaving Honours Chemistry from 1945 to 1951. During this time, he obtained three further degrees - a BA in 1935 in which he majored in Latin and English, a First Class Honours in Zoology in 1945 (after completing Zoology I, II and III in 1941, 1943 and 1944 respectively) and an MSc in 1947.

However, it was his broad interests and sense of humour combined with his great teaching ability that endeared him to his students. He was interested in sport, particularly tennis and hockey at which he excelled, acting, singing and the arts.

During his last few years at Adelaide High School Stan became interested in Zoological research and began a series of collaborative studies with T. Harvey Johnston, the Foundation Professor of Zoology at Adelaide University and a noted Parasitologist. These studies on Australian Acanthocephala (spiny-headed worms parasitic in the alimentary canals of various fish, birds and mammals) were first published in 1947 and continued for several years after Professor Johnston's death in 1951. During this period Stan widened his interests to include free-living marine organisms and in 1948 had a paper published on "The common species of animals and their distribution on an intertidal platform at Pennington Bay, Kangaroo Island". These mounting interests in Zoology led in 1952 to his resignation from the Education Department to take up an appointment as a lecturer in the Zoology Department, University of Adelaide under the newly-appointed Professor of Zoology, W. P. Rogers, an authority on the physiology and biochemistry of parasitic nematodes.

It was at this time that I had the pleasure of meeting Stan as I had been appointed to the Zoology Department as a Demonstrator earlier that year. One always associated him with laughter or at least a smile. His miming of sewing his fingers together and then threading the needle through various parts of his arm so that the whole could be moved mechanically by pulling on the thread, was always demanded of him at departmental parties and was always accompanied by gasps of horror from the faint-hearted and much amusement from the initiated.

Later, in his chapter on Zoology in "Ideas and Endeavours. The Natural Sciences in South Australia" Stan described what a busy time his early years in the Zoology Department had been, as student numbers were increasing rapidly and Rogers was building the Zoology Department. Needless to say, in this chapter, Stan gave himself scarcely any mention.

In addition to broadening his taxonomic interests, describing new species of Australian marine invertebrates, notably sipunculans and echinurans, Stan began to conduct a range of physiological and biochemical experiments on them. These physiological experiments were extended to the parasitic acantho-

cephalans and to the species *Moniliformis dubius* in particular. This species was maintained in the laboratory in cockroaches, the intermediate host, and rats, the primary host. The distinctive rustle and odour of Stan's experimental cockroaches, as one entered the constant temperature room in which they were housed, are sounds and smells not easily forgotten! The nutrition and egg laying of these animals were studied and reported upon and, together with B. R. Dixon, a paper was published in *Nature* on the uptake of small particles through the body wall of *M. dubius*.

Around this time Stan collaborated with H. B. S. Womersley in what was the first significant paper on the intertidal ecology of South Australia. It was also the first paper published on this topic in Australia that dealt in equal detail with both flora and fauna. Furthermore, it dealt with the relatively sheltered coastline of South Australia which, with its gulfs and bays and Kangaroo Island, differed from the more exposed coastline of the Eastern States. In the light of their work Womersley and Edmonds were able to supply evidence, previously unavailable, for the biogeographical nomenclature of the southern Australian coastline.

In addition to his researches on intertidal ecology, Stan also worked with Marian Specht on ecological studies of heathland in the Keith region of South Australia. This work involved monthly visits over a period of three years between 1952 and 1954 and resulted in the accumulation of a vast amount of information that permitted judgements to be made on the faunal rhythms of heathland in South Australia.

In 1958 Stan's researches on sipunculans resulted in his being awarded a PhD.

Stan Edmonds' work on the Public Examinations Board, a member from 1960 to 1974, Chief Examiner in Biology for ten years and deputy Chairman from 1973-1974, was a measure of the regard in which his teaching experience was held.

Stan was to continue to undertake research on the sipunculans and the somewhat similar echiurans for many more years. In 1972 he co-authored a book with his late friend Dr A. C. Stephen of the Edinburgh Museum entitled "The Phyla Sipuncula and Echiura"

At the time of Dr Stephen's death, much remained to be done and it was recognized that Stan was the only person who had the scholarship and energy to complete this task. His share of this important contribution to marine studies was a large one, bringing information up to date and checking descriptions, records and translations with original specimens and data. He arranged species into genera, provided keys for identification and was alone responsible for the sixty full page illustrations. Some 320 species of sipunculans and 130 species of echiurans had been described at the time this 527 page book was published by the Trustees of the British Museum (Natural History) London. It was the first systematic monograph of the two phyla to be published this century and is likely to remain the standard reference work for many years to come.

Stan retired from the University of Adelaide in 1974, having been made a Reader in Zoology in 1973. He became an Honorary Associate of the South Australian Museum and over the next twenty years published a further thirty papers including several chapters in books. He was a strong supporter of the Royal Society of South Australia Inc., occupying the positions of Council member, Secretary, Vice President and becoming President in 1965. In 1982 he was awarded the Society's Sir Joseph Vero Medal for his distinguished scientific researches.

In conclusion I quote from C. M. Ward MA, a Latin teacher and scholar of high repute and, at the time, Acting Principal of Adelaide High School who wrote on 17 September, 1948 the following words. "Mr Edmonds has a lively, genial personality, a good sense of humour and a resourceful cultured mind. He is of strong, independent character but always friendly and unassuming. His honesty and integrity are unquestioned". A most fitting tribute to a much liked and respected personality who maintained these traits throughout his life.

Stan Edmonds is survived by his wife Barbara (née Ey) and a daughter Elizabeth.

ALAN F. BIRD

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TRANSACTIONS OF THE

ROYAL SOCIETY

OF SOUTH AUSTRALIA

INCORPORATED

VOL. 120, PART 3

THE BREEDING BIOLOGY OF LITORIA SUBGLANDULOSA AND L. CITROPA (ANURA: HYLIDAE), AND A RE-EVALUATION OF THEIR GEOGRAPHIC DISTRIBUTION

By MARION ANSTIS & MURRAY J. LITTLEJOHN†*

Summary

Anstis, M. & Littlejohn, M. J. (1996) The breeding biology of *Litoria subglandulosa* and *L. citropa* (Anura: Hylidae), and a re-evaluation of their geographic distribution. Trans. R. Soc. S. Aust. 120(3), 83-99, 29 November, 1996.

The known range of *Litoria subglandulosa* is extended and that of *L. citropa* is revised. Population trends observed at the type locality during the 1960s-70s and 1990s are compared.

The advertisement call, adult colouration in life, behaviour and embryological development of *L. subglandulosa* are described and compared with those of *L. citropa*. The single egg mass of *L. subglandulosa* shows adaptation to the lotic environment, being compact and strongly adherent. The embryos and larval stages of the two species are very similar in shape and colour in life from stage 17 onwards, but are readily distinguishable by mouthparts. Comparative notes on larval behaviour are given.

Key Words: *Litoria subglandulosa*, *Litoria citropa*, distribution, population trends, advertisement calls, oviposition, embryology, larval behaviour.

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KEY WORDS: *Litoria subglandulosa*, *Litoria citropa*, distribution, population trends, advertisement calls, oviposition, embryology, larval behaviour.

Introduction

Litoria subglandulosa was described as *Litoria glandulosa* Tyler & Anstis, 1975 but renamed because of primary homonymy (Tyler & Anstis, 1983). A member of the *L. citropa* species group (Tyler & Davies 1978), *L. subglandulosa* was previously known only from the Queensland/NSW border south to the New England ranges of northern NSW (Tyler & Anstis 1975). The type description included a description of the larvae, but no data were available on oviposition, embryological development, larval behaviour or the advertisement call.

The species was found 160 km south of its previous known distribution in the mid-north coastal ranges and Barrington Tops region by one of us (M.A.), in 1977. Its presence there and the absence of *L. citropa*, prompted a re-examination of the distribution of both species. In addition, observations on oviposition, the morphology of embryos, larvae and adults and a comparison of the advertisement calls of *L. citropa* and *L. subglandulosa* were made and are reported here.

Materials and Methods

Litoria subglandulosa

Adult specimens examined: Australian Museum (AM) R17577, 35525, 42934-35, 50163, 51096-7, 51104, 5173549. Point Lookout; R34458 - 14km East of Ebor; R36724 - Oakley Creek near Ebor;

R36975 - Guy Fawkes River, Ebor; R71109-71114 - Back Creek (Barwick River) near Point Lookout; R37017 - 5km S of Waleba; R39056 - 50km E of Glen Innes (Gibraltar Range); R52931 - Sandys Creek, Dorrigo; R51178-80 - Styx River, Point Lookout; R76519 - Gloucester Tops; R31683 - Upper Allyn River, Barrington Tops; R104932 - Ellenborough River, Bulga State Forest, NSW.

Litoria citropa

Adult specimens examined: Australian Museum R7560, Orbost; 7562, Aberfeldy, Vic.; 19237, 18234, 18236, 18238 Stanwell Tops; 79436, Stanwell Park; 24500-24505, 27590, Fauleonbridge; 45858, Thirlmere Lakes; 31685, 7112, 78927 Helensburgh; 45424, Tianjara Falls; 5188, Megalong Valley; 7110, Hazelbrook; 5008, Blackheath; 69034, Bell, Kurrajong Rd.; 76625, 18 km N of Lithgow; 8459, Pennant Hills; 14495, Colo Vale; 79100, 76623, Culoul Range N of Colo Hts.; 4261, Bundanoon; 71898, 24 km N of Moss Vale; 15462, Gosford; 78264-26, 78698, Kuringai-Chase; 60425, Nudgee Reserve; 79439, Galston Gorge; 7563, Manly, NSW.

Three adults cited as *L. citropa* by Tyler & Anstis (1975) from Barrington Tops localities:- Dept Zool., Univ. Melbourne (MUZD) 1792/64 - Upper Allyn and MUZD 1690-91/63 - Wombat Creek, were re-examined because of apparent overlap in range with the Barrington Tops localities for *L. subglandulosa*. These specimens have since been registered by the National Museum of Victoria (NMV) as D32666 (Upper Allyn River) and D32664-65 (Wombat Creek). Similarly, two specimens (NMV D6709-10), cited by Copland (1957) as *L. citropa* from near Grafton, north-eastern NSW, were examined.

* 26 Widesview Rd Berowra Heights NSW 2082.
† Department of Zoology, University of Melbourne,
Parkville, Vic. 3052

TABLE 1. Details of localities, habitats and field observations for *Litoria subglauclausa*.

No.	Locality	Alt.(m)	Habitat/Weather	Date/Time	Adults Calling	Temp. (dry, bulb; dry/wet/ water °C)	Larval Stages (L.sub.)	Larvae of Other Species Present
1	9.8 km E of Elands NSW 31° 36' 59" S 152° 24' 00" E	680	Permanent flowing stream, basalt/sand. Semi-cleared wet sclerophyll forest.	19.i.1977 2010 h 20.i.1977 1100 h 16.i.1996 1020 h	- - -	- - 20/19.5/16	25-42 25-42 Nil	<i>Mixophyes balbus</i> <i>M. fasciolatus</i> <i>L. pearsoniana</i> <i>Crinia signifera</i> <i>L. pearsoniana</i>
2	Turrill Creek, Bulga State Forest NSW 31° 31' 49" S 152° 08' 21" E	520	Permanent flowing stream, metamorphic/sand. Rainforest, overhead canopy. Light rain, overcast after good rain on 3.x.1980	28.xii.1979 - 2.x.1980 am/pm 4.x.1980 1800-1930 h 7.xii.1980 1545 h 8.xii.1980 pm 9.xii.1980 0720 h 20.i.1994 am pm 16.i.1996 1400 h	Diurnal calling 3+ ♂♂ 6 ♂♂ 1 gravid ♀ 1 ♂	- - 16-17 - 15/14.75 Water 15 22 19.5/18.5 27/24/19	26-46 (many at stage 46 No search 30-42 30-42 30-42 40-44 (6 only) 39-42 (7 only) 32-38 Nil	<i>M. balbus</i> <i>L. pearsoniana</i> No search <i>M. balbus</i> <i>L. pearsoniana</i> <i>M. balbus</i> <i>L. pearsoniana</i> <i>L. phyllochroa</i> <i>M. balbus</i> <i>L. lesueuri</i> <i>L. pearsoniana</i> <i>M. balbus</i> <i>M. balbus</i>
3	Ellenborough River Bulga State Forest NSW 31° 35' 31" S 152° 12' 09" E	610	Permanent flowing stream, basalt/sand. Wet sclerophyll forest.	1.i.1980 pm 5.x.1980 pm 6.x.1980 1300 h	- 8 ♂♂ 1 gravid ♀	- - -	32-38 Nil Nil	<i>M. balbus</i> <i>M. balbus</i>
4a	Frenchs Creek Bulga State Forest NSW 31° 33' 35" S 152° 11' 27" E	580	Permanent flowing creek, metamorphic/sand. Wet sclerophyll forest.	7.xii.1980 1915 h	3 ♂♂	16/15.5	No search	<i>M. fasciolatus</i> <i>L. pearsoniana</i> <i>L. phyllochroa</i>
4b	As above 31° 33' 40" S 152° 12' 26" E	520	As above	7.xi.1980 1945 h 8.xii.1980 pm 20.i.1994 pm 16.i.1996 1600 h	2 ♂♂ 1 ♂ - -	16/15.5 15 22 23/20/18.5	" Nil 28, 37 (2 only)	As above Nil <i>L. pearsoniana</i>

TABLE 1. *Continued.*

5a	Dilgry Creek Barrington Tops NSW 31° 59' 19" S 151° 33' 28" E	1180	Permanent flowing small creek, basalt/sand Wet sclerophyll forest. Hot, dry day, brief storm.	25.xii.1979 1400 h	-	-	26-41	<i>M. balbus</i> <i>C. signifera</i>
5b	Dilgry River Barrington Tops NSW As above 31° 53' 23" S 151° 32' 17" E	1160	Permanent flowing stream, basalt/sand. Wet sclerophyll forest. <i>Eucalyptus. Casuarina. Acacia</i> . <i>Leptospermum</i>	25.xii.1979 1430 h 26.xii.1979 pm 20.x.1994 am	- 1 ♂ groups of 3 ♂♂	- - 23	26-41 - -	<i>C. signifera</i>
6a	Polblue Creek Barrington Tops NSW 31° 53' 18" S 151° 25' 57" E	1450	Permanent flowing creek, basalt. Montane swampland. <i>Eucalyptus pauciflora</i> . <i>Danthonia</i> (tussock grass)	20.x.1994 1900 h 26.xii.1979 1400 h	undercover 40 ♂♂ in 3 groups of up to 6	9.8 Water 13.4	- 26-43	<i>M. balbus</i> <i>C. signifera</i>
6b	As above 31° 55' 38" S 151° 23' 14" E	1230	Permanent flowing creek, basalt. Montane forest.	19-20.xii.1994 pm	6 ♂♂	-	No search	-
7a	Manning River Barrington Tops NSW 31° 52' 53" S 151° 29' 21" E	1190	Permanent river, wet sclerophyll forest	26.xii.1979 pm	-	-	26-43	<i>M. balbus</i> <i>C. signifera</i>
7b	As above 31° 52' 52" S 151° 29' 34" E	1220	As above. Clear sky, gusty winds Very strong winds	6.xi.1994 2030 - 2121 h 7.xi.1994 0742 h	5 ♂♂ 4 ♂♂	15 Water 13.5 -	- - -	-
8	Tuckers Creek Barrington Tops NSW 31° 51' 58" S 151° 39' 12" E	750	Permanent stream, basalt. Wet sclerophyll forest	4.xi.1994 1400 h	2 ♂♂	16.8 Water 9.4	8 egg masses	<i>M. balbus</i> <i>C. signifera</i>
9	Fal Brook Mount Royal State Forest Barrington Tops NSW 32° 09' 42" S 151° 18' 46" E	750	Permanent stream, wet sclerophyll forest.	8.xi.1992	1 ♂	-	No search	No search

TABLE 1. *Continued.*

No.	Locality	Alt.(m)	Habitat/Weather	Date/Time	Adults Calling	Temp. (dry, bulb; dry/wet/ water °C)	Larval Stages (L. sub.)	Larvae of Other Species Present
10	Back Creek (Barwick River) Point Lookout NSW 30° 29' 29" S 152° 20' 38" E	1340	Permanent stream, basalt/sand, partly cleared grazing land. Montane wet sclerophyll forest	1.i.1972 1415 h 29-30.xii.1973 am/pm 5.i.1974 2115 h 19.xii.1994 1700 h	2 ♂ ♂, 7 juveniles 10 + ♂ ♂ 2 gravid ♀ ♀ 2 ♂ ♂ Nil	22 Water 23 - 15.5-14 - -	25-46 25-46 25-46 Nil	<i>M. balbus</i> <i>C. signifera</i> <i>L. booroolongensis</i> <i>L. pearsoniana</i> As above None present
11	Styx River Point Lookout NSW 30° 30' 34" S 152° 21' 56" E	1320	Permanent river, basalt/sand, partly cleared grazing land. Montane wet sclerophyll forest.	26.xii.1973 am	-	- Water 15	25-43	<i>M. balbus</i> <i>C. signifera</i> <i>L. pearsoniana</i> <i>L. booroolongensis</i> None present
12	Mobong Creek Wild Cattle Creek State Forest NE Dorrigo NSW 30° 10' 29" S 152° 53' 48" E	510	Permanent stream, basalt/sand. Wet sclerophyll forest, <i>Eucalyptus</i> , <i>Ceratopetalum</i> , <i>Acacia</i> .	19.xii.1994 1720 h 19.xii.1994 1500 h	- -	- 25.5/18/24	Nil 25-27	<i>M. iteratus</i> . <i>M. balbus</i> <i>L. pearsoniana</i> <i>L. booroolongensis</i> <i>L. chloris</i>
13a	Upper reaches Dichard Creek 32km E Glen Innes NSW 29° 40' 04" S 152° 03' 25" E	980	Permanent small creek, granite/quartz/sand. Dry sclerophyll forest. <i>Eucalyptus</i> , <i>Acacia</i> , <i>Pteridium</i> , <i>Blechnum</i> ferns.	20.x.1993 2200 h	1 ♂ (recorded)	13	No search	No search
13b	As above 29° 40' 12" S 152° 03' 38" E	940	As above. Warm, sunny day.	20.xii.1994 1400 h	-	34 Water 22	27-32	Nil
14	Coombadjha Creek, Washpool Nat. Park NE Glen Innes NSW 29° 28' 24" S 152° 19' 11" E	770	Permanent river, granite, quartz, gravel, sand. Rainforest. <i>Ceratopetalum</i> , <i>Eucalyptus</i> , <i>Acacia</i> , <i>Acmena</i> , <i>Quintinia</i> , <i>Cyathea</i> , <i>Todea</i> etc. Warm, sunny day.	21.xii.1994 1400 h	-	28 Water 22	36-43	<i>M. balbus</i> <i>L. pearsoniana</i>

TABLE 2. *Observations on adult behaviour in relation to oviposition - Litoria subglandulosa*

Locality No. (See Table 1)	Date/Time	Weather	Temp. (dry bulb; dry/wet bulb, °C)	Surface Water Temp °C	Adult Activity/Site of Collection	Oviposition Site	No. of Eggs
10	30-31.xii.1973 am/pm	Clear Sky	15	-	Nocturnal: 7 ♂ calling beside stream. Diurnal: Gravid ♀ beside stream 2m from calling ♂. Calling in bag prior to amplexus	In plastic bag attached below surface	292
	1.i.1974 0100-0930		-	16	Oviposition		
3	5.x.1980 pm	Clear sky, Rain previous night	16-17	8	8 ♂ calling		
	6.x.1980 1300	Clear, sunny	19	-	Gravid ♀ on log just above streamside in daylight. Calling ♂ collected here previous night		
	6.x.1980 0300-0900	As above	-	-	Oviposition	In plastic bag	425
2	7.xii.1980	Clear, sunny	-	-	Gravid ♀ on rock just above streamside	-	-
4a	7.xii.1980 2145	Clear sky	16.5/15.5	-	2 ♂ calling on branch 3m above water. 1 collected	-	-
4b	7-8.xii.1980 2200-0900		-	-	Oviposition - ♀ from loc. 2, ♂ from loc. 4	In plastic bag	-
5b	20.x.1994 0630	Warm, clear, no rain previous nights	8.5	9.3	Diurnal: ♂ calling undercover in groups of up to 3, along 150 m section of stream.	-	-
	1900	Some night fogs	9.8	13.4	Nocturnal: 40 ♂ calling from branches, vegetation beside stream in groups of up to 6	-	-
8	4.xi.1994 1130	Rain previous few days	16.8	9.4	2 ♂ calling	8 egg masses, each attached just below surface to leaf, twig, rock in flowing water of pools	-

TABLE 3. *Observations on adult behaviour in relation to oviposition - Litoria citropa*

No.	Locality	Alt. (m)	Date/Time	Weather/Temp.(dry bulb, °C)	Adult Activity	Oviposition Site	No. of Eggs
15	Maddens Creek Darkes Forest NSW 34° 13' 02" S 151° 00' 00" E	350	30.x.1972	Overcast night after one week of rain. 17	1 gravid ♀ collected on road 50m from stream.	-	-
			2.xi.1972	Overcast night after rain. 17	4 ♂♂ calling beside stream. 1 ♂ placed in plastic bag with ♀. Amplexus, but no eggs.	-	-
			6.xi.1972	Overcast night after storm. 19.5	3 ♂♂ calling. 1 gravid ♀ beside stream. 1 ♂ placed with ♀ in bag. Oviposition	Eggs scattered over bottom of bag.	890
			16.ix.1975	Overcast night light rain. 18	10 ♂♂ calling 2 gravid ♀♀. 1 ♂ placed in bag with 1 ♀. Oviposition	Scattered over floor of large dish of water in cage.	928
16	Ourimbah Creek Ourimbah NSW 33° 19' 09" S 151° 17' 53" E	50	25.xi.1973	Dry, warm, partly overcast night	1 ♂, 1 gravid ♀ sitting near each other beside stream. Placed in bag. Oviposition	Scattered over bottom of bag	655

Oviposition and embryos

Observations on three captive breeding pairs of each species, collected by M.A., are summarised in Tables 2 and 3. In each case, a calling male was first collected at night, then a gravid female was found during daylight the next day, in the same vicinity as the male. The pairs were each placed in a large inflated plastic bag containing stream water, a flat rock and aquatic vegetation. The bag was covered with opaque material for the duration of amplexus.

Litoria subglandulosa

Stages 1-25 (Gosner, 1960) were studied from three separate egg masses, one from the type locality (locality 10, Table 1), and the others from the new localities 3 and 4b. Hereafter, numbered localities will refer to Table 1 (unless otherwise stated). Further samples from egg masses found in the stream at locality 8 were maintained until stage 25 to confirm identity, by Dr A. White of the National Parks & Wildlife Service, NSW (NP&WS). Embryos and larvae were held in dishes (40 cm diam.) containing stream water, rocks, sediments and aquatic vegetation, and maintained at 14°-21°C (locality 9), and 15°-24°C (localities 3 and 4b).

The egg mass from locality 4b laid on 7.xii.1980 (Table 2), was submerged within a metal tea strainer in the cool, flowing water of the stream for the initial two days of development, but both the egg masses from localities 3 and 4b were maintained at higher temperatures of up to 24°C away from the stream from the third day after deposition. Embryonic development was observed under a Wild M5 stereoscopic microscope.

Litoria citropa

Stages 1-25 were studied from two egg masses from Darkes Forest and one from Ourimbah (localities 15 & 16, Table 3). Samples of eggs found scattered over the substrate in the stream were raised to stage 25 to confirm identity. Adults in breeding condition were placed in an inflated plastic bag covered with opaque material during amplexus and the resulting embryos maintained at 16°-23°C.

Larvae

Tadpoles were measured (to 0.1 mm) with vernier callipers and an ocular micrometer attached to the microscope. They were anaesthetised in Chlorbutol solution before preservation in 3% formalin. The staging system is that of Gosner (1960). Abbreviations for larval measurements shown in Table 6, follow Anstis (1976): TL = total length, BL = body length, BD = maximum body depth, TD = maximum tail depth, TM = tail musculature depth (measured in line with TD), IO = interorbital space, IN = internarial span, EN = the distance between eye

and naris and MW = maximum mouth width. Illustrations were made using a drawing tube attached to the microscope. Preserved and living larvae of *L. subglandulosa* from sites 1-9 were examined for comparison with those from the type locality and measurements are given in Table 6. Feeding and swimming behaviour of several larvae of both species was observed in captivity and in their natural lotic environment.

Advertisement calls

The calls of *L. subglandulosa* were recorded at a tape speed of 4.76 cm/sec¹, using a Sony TC-D5PRO portable cassette recorder with a Uher M516 microphone and a Grampian parabolic reflector. Calls of *L. citropa* were recorded with a Nagra 4.2 open-reel tape recorder at a tape speed of 19 cm/sec¹, and a Beyer M-88 cardioid dynamic microphone.

For *L. subglandulosa*, the tape cassette was replayed on a Nakamichi Dragon tape deck, and for *L. citropa*, the open-reel tape was replayed on either a Revox B-77 or a Sony TC-510-2 tape recorder. The calls were analysed on a Kay Elemetrics Digital Sona-Graph, Model DSP-5500. Additional analyses of waveforms were made by way of a Sound-Blaster 16 card (Creative Technology) installed in an IBM PC-compatible desktop computer, and using the Wave Studio (Creative Technology) and Spectra Plus Professional, Release 3.0 (Pioneer Hill) software. Both systems yielded consistent results for analysis of the same signals.

The dominant (= peak) frequencies were calculated as those of greatest amplitude in a power spectrum or an averaged spectral display. Numbers of pulses were determined by inspection of waveforms. Pulse rates were calculated from the interval between the peak of the first pulse and the peak of the last pulse in a pulse train and the number of pulses reduced by one (i.e., $n-1$ pulses). Because of the difficulty in determining the beginnings and ends (i.e., zero amplitudes) of pulses and pulse trains, the peak - peak interval was taken as the duration. Where appropriate, pulse trains are termed 'notes'. If two distinctly different types of temporal unit are present in a call, then the signal is described as diphasic (*sensu* Littlejohn & Harrison 1985).

Results

Distribution and habitat

Litoria subglandulosa

The new localities (1-9) recorded in Table 1 extend the known southern range of this species about 180 km. All localities are permanent streams/rivers of basalt or metamorphic rock country associated with rainforest, montane or wet sclerophyll forest (except for 13a & 13b) and are at 510 m or higher. The

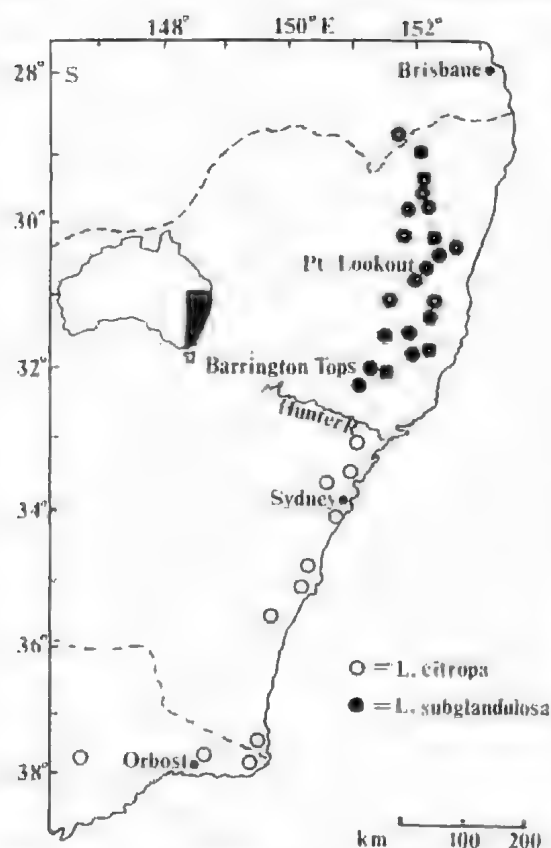


Fig. 1. A revision of the distribution of *Litoria citropa* and *Litoria subglandulosa* provided by Tyler & Anstis (1975), including a number of new localities for *L. subglandulosa*.

southernmost locality at which the species has been found is locality 9, Fal Brook, Mount Royal State Forest, NSW. The National Parks & Wildlife North-east Forests Biodiversity Study (1991-1994) records *L. subglandulosa* at a number of sites between the Barrington Tops region and the northernmost forests of NSW, including Doyles River State Forest, Mt Boss State Forest, Nowendoc, Werrikimbe National Park, Gibraltar Range National Park, Styx State Forest, Spirahn State Forest and Boonoon State Forest. This indicates the species has a fairly continuous distribution along the range country, from locality 9 in the south to near Stanthorpe, just north of the Qld/NSW border (151° 40' 30" E, 28° 40' 20" S) (Fig. 1).

On a daytime visit to localities 10 and 11 on 19.xii.1994, no tadpoles of this or other species were located. This was at a time when numerous tadpoles of *L. subglandulosa*, *L. boonoonensis* and *Mixophyes balbus* would be expected to be present (based on annual studies in the 1960s and '70s).

Observations by John de Bayay and Paul Webber confirm that there has been little evidence of this frog over recent years at the type locality, suggesting that the species may be undergoing a decline there. The National Parks and Wildlife Biodiversity Study has records of five males of this species calling at three sites on 2.ix.1995 in the Styx River State Forest in the region of the type locality:

- 1) Eely Creek - lat./long. 30° 34' 39" E, 152° 14' 43" S, (altitude 1060 m)
- 2) Eely Creek - 30° 35' 26" E, 152° 13' 18" S, (890 m)
- 3) Wattle Flat Camping Area - 30° 35' 28" E, 152° 12' 38" S (870m).

Observations on 20.xii.1994 at localities 12, 13b and 14 (all northern localities), indicated the presence of *L. subglandulosa* tadpoles.

Litoria citropa

Specimens NMV D32666 (Upper Allyn River) and D32664-65 (Womhat Creek) were examined and, on the basis of the indistinct tympanum, prominent supratympanic fold and head width, were found to be *L. subglandulosa*. NMV D6709-10 cited by Copland (1957) as *L. citropa* from near Grafton in the north-east coast of NSW, form the basis of the statement by Heatwole *et al.* (1995) that *L. citropa* "extends from northeastern New South Wales to southeastern Victoria". Upon examination, these specimens were found to have the body proportions of *L. subglandulosa*, but because both were collected in 1865 and in a poor state of preservation, it is difficult to come to a definite conclusion as to their identity. The two species have not been found in sympatry at any site examined, and this fact, in combination with the examination of museum material, indicates that the drainage of the Hunter River appears to be a natural geographic barrier separating them (Fig. 1).

Larvae were observed by M.A. on 1.i.1976 and 25.i.1996 at Boardinghouse Dam in the Watagan State Forest, south of the Hunter river NSW (33° 00' 01" E, 151° 24' 15" S) and by R. Wells further north in the Pokolbin State Forest, near Cessnock, in January 1993. This is the northernmost known locality for this species.

Litoria subglandulosa appears to replace *L. citropa* in the Barrington Tops region north of Newcastle (Fig. 1). *L. citropa* occupies a wider variety of habitats than *L. subglandulosa*, including permanent streams in basalt country associated with wet sclerophyll or montane forest, to similar streams in sandstone country. Although found at an altitude of 1066 m at Aberfeldy, Vic. and Blackheath, NSW, *L. citropa* also has been found in lower coastal areas to 50 m (locality 16, Table 3).

*Adult colour in life**Litoria subglandulosa*

Specimens from northern localities were predominantly green, whereas those from mid-north coastal localities (1–9) ranged from uniform golden brown with scattered darker mottling over the dorsum, to specimens with some small areas of green, often along the canthus rostralis or under the eye. Two males from locality 1 each had a broad dorsal patch of green over the head or dorso-lateral regions. Two specimens, AMR76519, from Gloucester Tops NSW and another observed by H. Hines (NP&WS) at Fal Brook (locality 9), were uniform bright green, apart from the characteristic golden dorso-lateral stripes.

Some golden-brown specimens developed large bright green patches over the dorsum at night (S. Gow pers. comm.). The inner surfaces of the hind limb and groin area were translucent yellow, as found in adults from the type locality.

Litoria citropa

Litoria citropa has a uniform golden brown dorsal colouration (with green along the canthus rostralis and sides of the body), similar to most specimens of *L. subglandulosa* from localities 1–9. The principal difference between the species is the colour of the inner surfaces of the hind limb and groin, which in *L. citropa* is brick red.

*Calling activity**Litoria subglandulosa*

Calling begins in spring and was observed on 20.x.1994 at locality 8, when water temperatures at night were very low, e.g., 6°C, and the dry bulb air temperature at locality 5b (1900 h) was 9.8°C (A. White, S. Gow pers. comm.). Other observations by M.A. at the type locality during annual three-week periods (Dec/Jan. 1966–74), and at all other localities listed in Table 1, indicate that calling persists throughout December/January in a variety of weather conditions, with increased activity during, or after, light rain. Evening dry bulb air temperatures taken during periods of spring/summer activity at the localities in Table 1 were 13°C–19.5°C (mean 15.7°C). At the lower temperatures (13°–14°C), calling was less intense and by aural comparison only, notes were at a slower repetition rate.

Sporadic diurnal calling was common during the breeding season but males were most active at night. Diurnal calling took place from concealed positions such as under rocks or from within vegetation, either near the stream, or at times up to about four metres away from the water. A single male or a small number of individuals, called from as early as 0742 h (e.g., locality 7b). Nocturnal calling was initiated by one frog, normally followed by others in a

distinctly polyphonic chorus. The calls of frogs at the southern localities could not be differentiated from those of males at the type locality.

Males observed calling at night were often perched on broad leaves of trees and shrubs approximately 0.5–1.5 m above streams, on ferns at the edge of the stream, or on vegetation further from the water's edge. They were frequently found calling in small groups, two or more metres apart. On 22.x.1994 at locality 5b, 40 males were calling at night in groups of up to six along a 50 m stretch of the stream (S. Gow pers. comm.). At locality 7b on 7.x.1994, four males were calling 25 m apart (K. Thurnm pers. comm.).

An analysis of the advertisement call is provided below and comparison made with that of *L. citropa*. Two additional call sequences, attributable to *L. subglandulosa*, are in the Bioacoustic Library of the Department of Zoology, University of Melbourne, both recorded by M. J. Littlejohn and his associates. The first, from Guy Fawkes Creek Ebor NSW (30° 24' 20" E, 152° 20' 46" S), was recorded on 28.x.1964 at a wet bulb air temperature of 8.5°C, and the second, from Flat Rock Creek 8 km W of Point Lookout NSW (close to the first site), on 14.x.1968 at a wet bulb air temperature of 13°C. They are similar in all pertinent respects to the call described here.

Litoria citropa

Males at Darkes Forest (locality 15, Table 3) were observed during spring and summer calling from low branches beside the stream, on rocks near the edge of the water, or on exposed rock shelf in mid-stream close to shallow, slowly flowing water. As with *L. subglandulosa*, males called while two or more metres apart and activity increased on overcast evenings during or after rain. Dry-bulb air temperatures on several nights when males were calling in September–December, 1972–1980, were 14°–22°C. No diurnal calling was observed.

*Advertisement calls**Litoria subglandulosa*

The advertisement call of *L. subglandulosa* was recorded by J. Courtney at Diehard Creek, Glen Innes (locality 13a), on 20.x.93. The dry-bulb air temperature was 13°C. The following data were obtained from the fourth call in the sequence (Fig. 3A). The call has a duration of 9.375 s and consists of 13 pairs (doublets) of pulse trains (notes), with each of those in the first five pairs all being of relatively low amplitude (Fig. 3b). In the subsequent seven pairs of notes, the second note is of much greater amplitude than the first. Thus, all but one of the first notes (which is of equal amplitude) are softer, with the amplitude of second notes being



Fig. 2. Live egg mass of *Litoria subglandulosa* attached to a leaf from submerged overhanging foliage in Tuckers Creek, Barrington Tops (locality 8). Scale bar = 10mm.

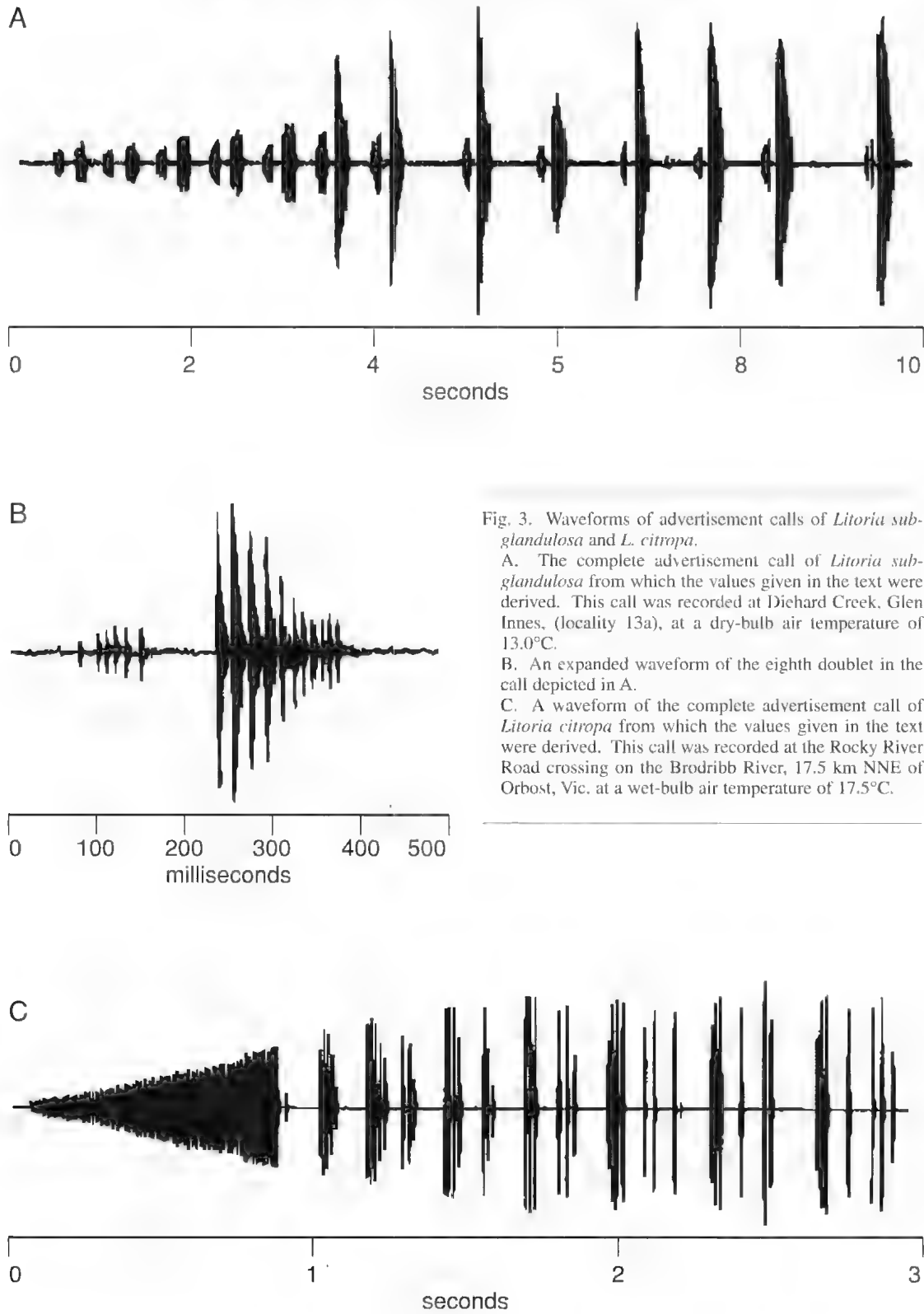


Fig. 3. Waveforms of advertisement calls of *Litoria subglandulosa* and *L. citropa*.

A. The complete advertisement call of *Litoria subglandulosa* from which the values given in the text were derived. This call was recorded at Diehard Creek, Glen Innes, (locality 13a), at a dry-bulb air temperature of 13.0°C.

B. An expanded waveform of the eighth doublet in the call depicted in A.

C. A waveform of the complete advertisement call of *Litoria citropa* from which the values given in the text were derived. This call was recorded at the Rocky River Road crossing on the Brodribb River, 17.5 km NNE of Orbost, Vic. at a wet-bulb air temperature of 17.5°C.

greater by up to 9 dB in pairs 1-7, and by 12 to 20 dB in pairs 8-13. Durations of doublets range from 291 to 372 ms (mean = 334); intervals between doublets range from 84 to 159 ms (mean = 118). The repetition rate of the doublets is 1.35 s^{-1} . The dominant or peak frequencies are within the range of 1360-1480 Hz, with means of 1405 Hz for the first notes and 1454 Hz for the second notes. There are 10-15 pulses (mean = 14.1) in the first notes of each of the first seven pairs, and 4-6 pulses (mean = 4.8) in the remainder, with 13-23 (mean = 16.1) in the second note of the first seven pairs, and 9-11 (mean = 10.3) in the remainder. Ranges of durations of first notes are 72-93 ms (mean = 85.9) for the first seven pairs, 43-69 ms (mean = 59.8) for the others and 126-149 ms (mean 137.6) and 134-159 ms (mean 144.2) respectively for the second notes. Pulse rates of first notes range from 125-167 p s^{-1} (mean 152.5) in the first seven pairs, to 46-85 p s^{-1} (mean 64.9) in the last six. For the second notes, the ranges for pulse rates are 92-182 p s^{-1} (mean 145.0) for the first seven pairs and 56-75 p s^{-1} (mean 64.9) for the last six.

Litoria citropa

The advertisement call of this species was described by Littlejohn *et al.* (1972) from the audiospectrographic and oscillographic analysis of two calls of one individual recorded (Nagra III B recorder, Electro-Voice EV 644 microphone) at Trough Creek 9 km W of Cann River Vic. (149° 05' E, 37° 34' S) on 24.x.1969. The male was calling on the bank at a wet-bulb air temperature of 10.5°C. Owing to background noise levels in the recording, only a tracing of a waveform was provided.

This relatively long call (3.2-3.6 s) was described as of complex temporal structure (i.e., strongly diphasic), with a long introductory note (910-970 ms) of high and regular pulse rate (46 p s^{-1}), followed by a sequence of irregularly produced pulses in groups of 5-7. The groups have durations between 80 and 120 ms and pulse rates of 34-57 p s^{-1} near the start, and are longer (245-500 ms) and of lower pulse rate (10-21 s^{-1}) near the end. The dominant frequencies range from 1350 to 1800 Hz within a broad band of frequencies between 1250 to 3600 Hz.

To confirm this description, and to provide an indication of possible effects of temperature, the last clear call in the recorded sequence of another individual of *L. citropa* was analysed. The recording was made at the Rocky River Road crossing on the Brodribb River 17.5 km NNE of Orbost Vic. (148° 33' E, 37° 30' S) by M. J. Littlejohn on 28.xi.1981. This frog was calling from vegetation at a height of about 50 cm, adjacent to the river, at a wet-bulb air temperature of 17.5°C. A wave form of this call is presented in Fig. 3C.

The call, which has an overall duration of 2.866 s,

consists of a distinct first note which is a regular pulse train with a duration of 814 ms, a pulse rate of 187 p s^{-1} and a dominant frequency of 1640 Hz. A single pulse (duration approximately 7.0 ms) with a dominant frequency of 1600 Hz follows. The remainder of the call consists of eleven groups of 3-5 pulses but four pulses and one pair of pulses cannot realistically be grouped to allow calculation of a pulse rate; otherwise, pulse rates range from 31 to 84 p s^{-1} . The dominant frequencies of these pulses range from 1200 to 1300 Hz, and the durations of the pulses range from 8.6 to 12.9 ms. The variable pulsatile second part of this call has a maximum amplitude about 5 dB higher than that of the introductory note.

Oviposition

Litoria subglaudivox

The advertisement call of the male was heard in the bag before amplexus occurred. Details of egg masses laid are presented in Table 2. Oviposition was not observed, but for each of the three captive pairs studied, a single egg mass was found adhering to the side of the bag, just below water level. The eggs were laid in a small, compact clump of two to three layers of extremely sticky, cohering capsules. Egg complements for two females were 292 and 425.

Another eight egg masses of this species were found at locality 8 on 4.xi.1994 by A. White and S. Gow. Each mass was attached to an overhanging leaf, a twig or a rock face in vertical or near vertical orientation, just below the water surface in a slowly flowing section of a pool (some in mid-stream). The pool was heavily shaded by an almost complete canopy cover. Steady rain had fallen three days earlier and the surface water temperature at 1400 h was 9.4°C. One of these masses, removed from the stream on a leaf and photographed, is shown in Fig. 2.

Litoria citropa

On 25.xi.1973, oviposition occurred after the male and female had been collected at Ourimbah Creek, NSW (locality 16, Table 3), at 2200 h. The frogs were placed in a plastic bag. The male soon began to call and the pair was in amplexus three hours after capture. At 0156 h on 26.xi.1973, the initial two sequences of oviposition activity occurred; at 0157 h, a further four oviposition sequences followed, with only about three seconds between each. Oviposition was complete by 0159 h.

In a typical sequence, the female dorsiflexed her body with outstretched hind limbs and produced a batch of eggs. The male fertilised them while cupping his feet in a fanning motion around the eggs. The female then scattered the eggs with three sudden kicking movements of her hind limbs. The eggs sank and spread in a single layer across the bottom. She

TABLE 4. Comparison of embryos of *Litoria subglandulosa* and *Litoria citropa*
Developmental stages are those of Gosner (1960)

Stage	Sample		Mean embryo diameter/length (mm)		Mean capsule diameter (mm)		Description	
	<i>L. subgland.</i> n	<i>L. citropa</i> n	<i>L. subgland.</i>	<i>L. citropa</i>	<i>L. subgland.</i>	<i>L. citropa</i>		
2	4	4	1.59	1.73	3.57	6.10	Animal pole: black/ vegetal pole: dark grey	dark brown/ creamy white
17	9	15	2.17	3.12	-	-	Body: dark grey, yolk sac light grey Head (lateral view): acutely angled Optic vesicle: small, distinct bulge Gills: anterior 3-4 branches posterior 4-5 branches	dark brown/ creamy white acutely angled larger, indistinct bulge 1-2 branches 2-4 branches (shorter)
21-22	3	9	6.53	6.76	-	-	Lateral lines: pigmented Mouth-parts: no tooth rows or keratinised jaw sheath Hatching time: 6-10 days	non-pigmented tooth rows, keratinised jaw sheath 4-6 days
24-25	1	8	7.39	9.65	-	-		

then swam to another site and the process was repeated. During the final sequence, the female remained in the dorsiflexed position about three seconds longer, but produced no eggs. The male then released the female at the point when she began kicking her hind limbs.

The egg complement was 655. Embryos hatched in four - five days at water temperatures of 17°-23°C. Two other egg masses laid in captivity contained 890 eggs and 928 eggs and took four - six days to complete hatching at 16°-23°C (see Tables 3 & 4).

In the field, the eggs were found scattered over the substrate in shallow pools or slowly flowing sections of the stream, which is similar to the mode of deposition of eggs observed in captive pairs.

Embryonic development

Litoria subglandulosa

Mortality rates of embryos maintained in captivity were high. The survival rate (after removal from the stream), was greatest amongst embryos in the top layer of each mass. Those below this layer mostly ceased developing beyond about stages 8-12. Embryos from the egg mass held at locality 10 in water temperatures of 14°-21°C, survived the longest; hatching occurred from days 8 - 10 and only 17 reached stages 20 - 25. The mass from locality 3 did not develop beyond stage 18. Initially, the embryos from locality 4b continued to develop during the two days of immersion in the stream before higher temperatures away from the stream were experienced. Hatching occurred at stages 20 - 21 from days 6-8, with only eight embryos surviving. Embryos from the southern localities match the following description of those from the type locality 10.

Embryos laid early on 1.1.1974 (locality 10) were at stage 2 when a sample was preserved at 0945 h. The animal pole is black and the vegetal pole dark grey. There are two layers of jelly surrounding the perivitelline membrane. Measurements of embryos are given in Table 5. The embryos were at stages 7-8 after 8 h, and 8-9, after 12 h. Six embryos at stages 7-8, measured after preservation, have a smaller mean diameter (than the same embryos measured live (1.7 mm live, 1.5 mm preserved; capsule diameter 3.6 mm live, 3.3 mm preserved). After 23 h, embryos were at stages 10-11, and after 38 h, at stages 12-13.

Stage 17 was reached after 62 h. A specimen drawn at stage 17 (Fig. 4A), is described:- prominent optic vesicle, pronephric swelling, slight anal bulge, large

TABLE 5. Dimensions of preserved embryos of *Litoria subglandulosa*
(mean in mm, range in parenthesis, stage - Gosner, 1960)

Stage	Sample	Embryo diam.	Capsule diam.
2	4	1.59 (1.56-1.64)	3.57 (3.12-4.51)
7-8	5	1.56 (1.56-1.56)	3.56 (3.36-3.85)
16	5	2.05 (2.05-2.05)	3.39 (3.28-3.53)
17	9	2.17 (2.13-2.34)	
20	6	5.80 (5.49-6.23)	
21-22	3	6.53 (6.48-6.64)	
23	2	6.80, 7.34	
24	1	7.39	

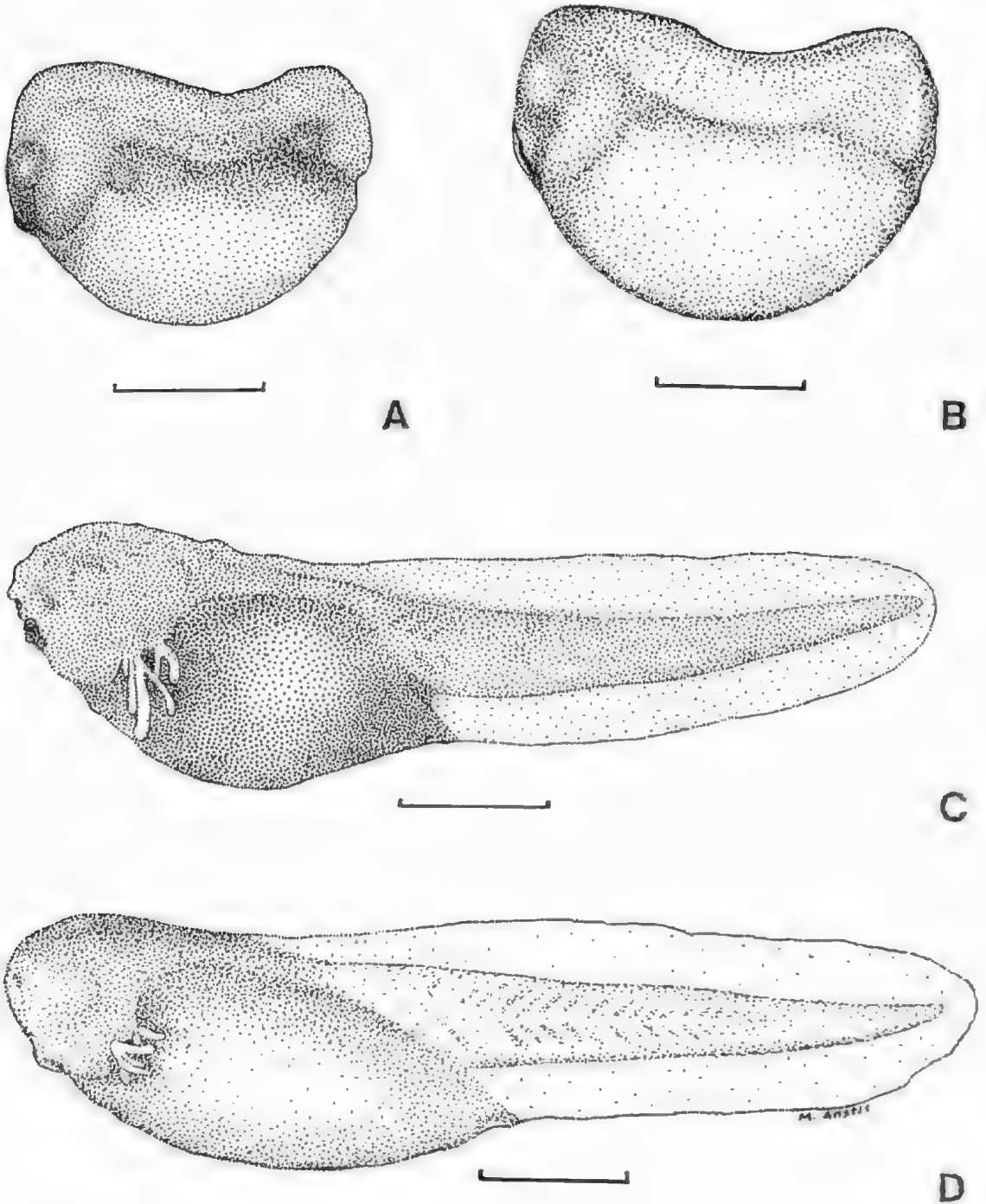


Fig. 4. Embryos of *Litoria subglandulosa* and *L. citropa*.
 A. *L. subglandulosa* removed from its capsule, at stage 17.
 B. *L. citropa* removed from its capsule, at stage 17.
 C. *L. subglandulosa* just hatched, at approximately stage 21.
 D. *L. citropa* just hatched, at approximately stage 21.
 Scale bar = 1 mm. Stages are from Gosner (1960).

gill-plate swelling, with beginnings of muscular ridges along dorsal surface just below neural tube. U-shaped adhesive organ; slight stomodaeal groove beginning to form. Head truncate, acutely angled in lateral view. Tail bud short, rounded, with strong depression on each side below neural tube. Yolk sac grey, rest of body very dark grey. After some years in preservation, body appears dark and yolk sac lighter brown.

Embryos examined at 71 h were in stages 17-18:- growing tail bud pointing acutely to the left side of the body within firm jelly capsule; two visceral arches forming; narial pits beginning to develop.

After 95 h, stage 18:- optic vesicle more defined with groove forming between this and gill plate; neural tube, dorsal muscular ridges, narial pits and divided adhesive organs all more developed.

After 131 h, stages 19-20:- small external gills, gill circulation not apparent; head small, more rounded over cranial region, adhesive organs diminishing; optic vesicle depressed slightly in ventre; live embryos dark grey dorsally, lighter grey over yolk sac, moving actively within capsule.

Hatching began eight days after oviposition; all surviving embryos had hatched after ten days. Embryos hatching first on day 8 were at stage 20 (in relation to optic development, but no gill circulation):- Optic vesicles indistinct, yolk sac large, deepened stomodaeal pit with adhesive organs close together at anterior end, a divided ridge at posterior end; gills developing, noticeably more advanced on sinistral side; vent tube not well differentiated; tail fins dusky grey, slightly arched dorsally; body dark grey brown in preservative, head region slightly darker.

Stage 21 was reached on day 10, in relation to gill development and lack of tail fin circulation only. (Fig. 4C):- two pairs of well-developed functional external gills, comprising 2-4 branches on anterior pair, 1-5 on posterior pair; adhesive organs small translucent; optic vesicle undefined; fins translucent, deepening further, circulation not apparent; tail musculature poorly developed.

Five final hatchlings at 1900 h on day 10 were at stage 22 in relation to tail circulation, but other development was associated with stages 20-21:- cornea still not transparent, prominent but only partially pigmented optic vesicle; tail fins deepening; gills at maximum development, fully functional, longer in some specimens than others; adhesive organs merging to form small ridge; mouth triangular; line of pigment from tip of snout through each narial pit to eye.

Stage 23:- cornea transparent, eyes well developed, heavily pigmented; anterior half of body becoming transparent around nares; gills diminishing, operculum developing.

Stage 24:- vent tube more discernible, oral disc developing, with small triangular funnel above large oval depression to become lower labium.

By day 13, most remaining embryos were at early stage 25:- golden iridophores scattered in spots over dorsum, eyes black with scattered golden iridophores, patches of melanin over dorsal surface of tail musculature; tail fins, body wall mostly clear, with some dusky pigment present. Internarial region noticeably delineated with pigment, lateral line organs becoming visible.

By day 17, the development of the mouth was almost complete with the exception of the fine black filaments, which were either not yet present, or only short unpigmented roots. Dorsal surface further pigmented with more golden iridophores over areas pigmented with melanin, including iris; tail musculature pigmented dorsally, in well-spaced broad bands; flecks of pigment found over fins in older larvae, as yet not obvious; ventral surface clear except for broad perimeter of iridophores.

Litoria citropa

Embryonic development was described by Tyler & Anstis (1975). A comparative summary of embryos of *L. citropa* and *L. subglandulosa* during stages 2, 17, 21 and 25 is given in Table 4. Figures 4B, D show stages 17 and 21. In general, *L. citropa* is larger than *L. subglandulosa* throughout embryonic development, with adhesive organs more prominent and gills smaller and less numerous at stage 21. At stage 25 and beyond, the lateral line organs remain unpigmented and mouthparts possess tooth rows and a keratinised jaw sheath (Fig. 4, Tyler & Anstis 1975). Otherwise, the two species have distinctly truncate, angular heads in stage 17 and similar body/tail shape throughout embryonic and larval development.

Larval behaviour

Litoria subglandulosa

Tadpoles of this species, observed at all localities in Table 1, were mostly found on the substrate in shallow, slowly-flowing sections of the stream on sand, amongst rocks or leaf litter. They were frequently found at the sides of the stream, swimming fast to deeper mid-stream or amongst rocks if disturbed. They were well camouflaged whilst on sand or grazing amongst rocks and appeared to feed on flocculent silt and algae. Tadpoles defaecated rapidly after capture and the abdominal region, while similar in width to the branchial region (or slightly less) in live specimens in the stream, was commonly narrower in preserved specimens.

Tadpoles observed adhering to the substrate rapidly pulled the body forward a distance of 2-3 mm

by the use of the oral disc alone, in a rasping action. This process was repeated continually, resulting in a distinctive form of locomotion during feeding, which has not been described in other Australian suctorial species. Particles of a fine silt suspension were found amongst the dense, incurved papillae, buccal cavity and gut of recently-captured specimens.

The fine black filaments of the mouth were broken or missing in some specimens, or each was present only as a shorter white filament or core, without the black outer surface (or pigmentation).

Litoria citropa

The tadpoles were found in small rock pools (either associated with the main stream or segregated when river levels were lower), and in larger pools or slowly flowing sections of the stream. They were also found on the substrate, but unlike *L. subglandulosa*, were not observed moving forward by the use of the mouth alone; the tail and body were also involved. They appeared to feed on flocculent silt and most individuals examined live in the streams, had well-filled intestines (the abdominal region being as wide as, or wider than the branchial region). When disturbed they took cover under rocks or leaf litter. They were well camouflaged on the sandy floor and the dorsal colour varied from light to darker golden brown, depending on the colour of the substrate and light intensity.

Discussion

Population trends

Comparative field observations of the 1960s-70s and 1990s showed a marked decline in the population status of *L. subglandulosa* at the type locality, indicating a need for comprehensive studies on population trends of this species across its entire distribution.

Advertisement calls

The calls of *Litoria subglandulosa* and *L. citropa* differ markedly in structure (Fig. 3A, C) and cannot be of any assistance in the confirmation of relationships based on other criteria. As noted by Watson *et al.* (1991), the audiospectrograms of the advertisement calls of *L. citropa* and *L. spenceri* are of similar diphasic structure; they differ, however, in that the following notes in the call of *L. spenceri* are more regularly pulsed and of higher pulse rate.

Oviposition and embryos

From observations of oviposition sites of *Litoria verreauxii*, *L. dentata*, *L. phyllochroa*, *L. caerulea*, *L. chloris*, *L. freycineti*, *Limnodynastes peronii*, *Lim. tasmaniensis*, *Lim. ornatus* and other species of Australian frogs, it has been noted that each deposits

TABLE 6. Comparison of body proportions of larvae of *Litoria subglandulosa*. Type Locality 10 compared with new localities 2, 6a & 7a (Table 1). (Measurements in mm; mean with range in brackets). Stages 35 & 36 (Gosner 1960).

Morphometric Character	Type Locality 10 n = 8	Localities 2, 6a, 7a n = 8
TL	29.84 (26.40-35.00)	31.50 (28.50-33.75)
BL	12.19 (11.64-12.63)	11.88 (10.82-13.13)
BW	7.42 (6.15-8.04)	7.64 (7.05-8.45)
BD	6.17 (5.74-6.64)	6.10 (5.58-6.72)
TD	5.86 (5.17-6.48)	5.87 (5.42-6.40)
TM	2.01 (1.64-2.29)	2.35 (1.89-2.71)
IO	2.49 (2.13-2.87)	2.75 (2.46-3.29)
IN	1.88 (1.80-1.97)	1.94 (1.80-2.05)
EN	1.46 (1.15-1.64)	1.37 (1.15-1.64)
MW	4.55 (3.77-5.25)	4.48 (4.10-5.00)

eggs in a similar manner whether in the field or in captivity (Anstis 1976, Anstis, unpub.). Similarly, *L. citropa* scatter eggs over the substrate in both captive and field situations, and *L. subglandulosa* attach the entire egg mass to a surface just below water level. The egg mass of *L. subglandulosa* is adapted to the lotic environment, being compact in form and highly adherent.

Embryos of *L. subglandulosa* that survived beyond stages 8-12 were mainly from the outside layer of capsules. Mortality may be attributed to reduced oxygen levels associated with higher still – water temperatures in the laboratory of up to 24°C, compared with 9.4°-15°C in flowing streams. The embryos from the egg mass at locality 4b continued development during the initial two days of immersion in the stream but, after removal and placement in the laboratory, development gradually ceased over the next four days in the majority of cases.

The periods of 6-8 and 8-10 days taken by two egg masses to hatch (while maintained in containers) are slower than those of other known stream-dwelling hylids of lower altitudes, including *L. citropa* (Tyler & Anstis 1975; Anstis unpub.). Further comparisons can be made when data are available for developmental rates of egg masses within the stream.

The egg capsules of *L. citropa* are not as adherent as those of *L. subglandulosa*. As they are scattered over the bottom of still pools or very slowly flowing sections of the stream, stronger adhesive properties

would not be advantageous. The embryos developed faster and had a much lower rate of mortality than those of *L. subglandulosa*, possibly attributable to the individual capsules being scattered over a broad area, facilitating oxygenation.

Larvae

Whilst slight differences in body proportions were noted between some of the northern and southern tadpoles of *L. subglandulosa* (Table 6), only a small sample from each area was examined.

A sample of *L. subglandulosa* tadpoles was also very difficult to maintain in captivity at higher temperatures and a second sample maintained in aerated water with filtration fared no better. Lacking keratinised jaw sheaths, they could not eat foods such as boiled lettuce and commercial fish food. Introduction of silt and detrital sediments taken from the streams in their natural environment resulted in some feeding, although the tadpoles did not grow as well as those in the streams.

The distinctive locomotive behaviour of the tadpoles involving forward propulsion with the use of the oral disc alone, distinguishes them from the similar sympatric species *L. phyllachna* and *L. lesueuri*, both of which employ some tail movement during locomotion associated with feeding. Gradwell (1975) states that the M3c muscle in *L. subglandulosa* tadpoles is inserted in both the upper and lower labia, resulting in both labia being "pulled

caudad simultaneously", whereas "most other suctorial tadpoles move their upper and lower jaws toward each other during their scraping action". This could explain the mechanism behind the distinctive movement observed in live tadpoles in the stream. Gradwell also notes that this species has, for its size, "the longest and densest papillae of the buccal mucosa", and these "may act as a sieve to exclude suspended particles above a certain size".

Examination of gut contents and further observations of feeding mechanisms are required to determine the functional morphology of the unique mouthparts of this species.

Acknowledgments

We are grateful to the Australian Museum and the Museum of Victoria for access to and loan of specimens. The NSW National Parks & Wildlife Service is acknowledged for permission to refer to records of *Litoria subglandulosa*. John Courtney provided the tape recording of *L. subglandulosa* analysed. Arthur White provided Figure 4, and with Karen Thummi, Jacquie Reese and the late Shane Gow, added valuable observations on *L. subglandulosa* to this study. David, Dulcie and Ron Anstis, John de Bavay and Roy Scott assisted with field work. Stephen Richards, Michael Mahony, John de Bavay, Fred Parker and Michael Tyler constructively reviewed the manuscript.

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STRATIGRAPHY OF THE NEOPROTEROZOIC ARUHNA AND DEPOT SPRINGS SUBGROUPS, ADELAIDE GEOSYNCLINE

*By IAN A. DYSON**

Summary

Dyson, I. A. (1996) Stratigraphy of the Neoproterozoic Aruhna and Depot Springs subgroups, Adelaide Geosyncline. *Trans. R. Soc. S. Aust.* (1996), 120(3), 101-115, 29 November, 1996.

The Sandison Subgroup of the Lower Wilpena Group is unconformably overlain by the Wilcolo Sandstone and, together with the Bunyeroo Formation, comprises the Aruhna Subgroup. The Bunyeroo Formation is in turn unconformably overlain by the Wearing Dolomite which, together with the overlying Wonoka Formation, is assigned to the Depot Springs Subgroup. A number of subgroups in the Umberatana and Wilpena groups is also capped by dolostones that display similar characteristics to the Wearing Dolomite of the Depot Springs Subgroup. The dolostones are interpreted as having been deposited on major, sediment-starved hiatal surfaces under cold water conditions, each of which is adjacent to either a major incised valley or submarine canyon fill. The differentiation of these unconformity-bounded subgroups is based on their recognition as genetic units in terms of sequence stratigraphy.

Key Words: Sequence stratigraphy, Neoproterozoic, Aruhna Subgroup, Depot Springs Subgroup, Bunyeroo Formation, Wearing Dolomite, Burr Well Member, Artipena Dolomite Member, Wilcolo Sandstone, Wonoka Formation, incised valleys, submarine canyons, dolostones, Adelaide Geosyncline.

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KEY WORDS: Sequence stratigraphy, Neoproterozoic, Aruhna Subgroup, Depot Springs Subgroup, Bunyerroo Formation, Wearing Dolomite, Burr Well Member, Artipena Dolomite Member, Wilcote Sandstone, Wonoka Formation, incised valleys, submarine canyons, dolostones, Adelaide Geosyncline.

Introduction

The stratigraphic nomenclature of the Adelaide Geosyncline emphasises the distinction between chronostratigraphic and lithostratigraphic units (Preiss 1987a). The positions of the chronostratigraphic units do not always correspond to lithostratigraphic boundaries. Some lithostratigraphic boundaries are unconformities and therefore assume chronostratigraphic significance, while others are mappable lithological changes of regional significance (Preiss 1987a). These differences between the two stratigraphies can best be accommodated by adopting a sequence stratigraphic scheme. It depends on the recognition of mappable rock units within a chronostratigraphic framework of repetitive, genetically-related strata bounded by unconformities or their correlative conformities. Thus, a revised stratigraphic nomenclature of Neoproterozoic successions in the Adelaide Geosyncline could be based on differentiation of subgroups within a sequence stratigraphic framework (Dyson 1992a, b, 1996a). Forbes & Preiss (1987) suggested there was merit in uniting related depositional units in a single subgroup.

Sequence analysis of the Umberatana Group (Dyson 1992a, 1995¹, 1996a, b) and Wilpena Group (von der Borch *et al.* 1988; Dyson 1992b) has led to the recognition of several unconformity-bounded depositional sequences. In a study of the Sandison Subgroup (Dyson 1995¹), stratigraphic units immediately overlying this sequence were examined in order to understand better the spatial and temporal relationships of the Lower Wilpena Group. The Sandison Subgroup is unconformably overlain by the Wilcote Sandstone and together with the Bunyerroo Formation is herein assigned to the Aruhna Subgroup. Similarly, the Bunyerroo Formation is unconformably overlain by the Wearing Dolomite and together with the Wonoka Formation is assigned to the Depot Springs Subgroup. The Sandison, Aruhna and Depot Springs subgroups (Fig. 1) are defined as genetic units that are considered major unconformity-bounded, depositional sequences in the sense of Mitchum (1977). Of particular significance is the nature of the Wearing Dolomite and its relationship to other Neoproterozoic dolostones or units that contain appreciable dolomite in the Adelaide Geosyncline, i.e., Nuccaleena Formation, Tindelpina Shale, Warowie Dolomite and the Artipena Dolomite Member (new name) of the Enorama Shale. The names "Wilcote Sandstone", "Aruhna Subgroup", "Depot Springs Subgroup" and "Artipena Dolomite Member" have been reserved by the Central Register of Australian Stratigraphic Names.

Aruhna Subgroup

In the southern and central Flinders Ranges, the ABC Range Quartzite is overlain with local

* National Centre for Petroleum Geology and Geophysics, University of Adelaide Adelaide S. Aust. 5005

¹ Dyson, I.A. (1995) Sedimentology and stratigraphy of the Neoproterozoic Sandison Subgroup: a storm-dominated shallow marine sequence in the Adelaide Geosyncline, South Australia. PhD thesis, Flinders University of South Australia (unpub.).

	MORALANA SUPERGROUP	HAWKER GROUP		EARLY CAMBRIAN
NEOPROTEROZOIC	HEYSEN SUPERGROUP	WILPENA GROUP	POUND SUBGROUP	MARINOAN
			DEPOT SPRINGS SUBGROUP	
			Wonoka Formation	
			Wearing Dolomite	
			ARUHNA SUBGROUP	
			Bunyerroo Formation	
			Wilcolu Sandstone	
			SANDISON SUBGROUP	
	WARRINA SUPERGROUP	UMBERATANA GROUP	▲▲▲▲▲▲▲▲	ADELAIDEAN
		BURRA GROUP	▲▲▲▲▲▲▲▲	
		CALLANNA GROUP		
			CURDIMURKA SUBGROUP	
			ARKAROOA SUBGROUP	
	ARCHAEOAN & PALAEOPROTEROZOIC COMPLEXES			Pre-ADELAIDEAN

Fig. 1. Stratigraphy of the Aruhna Subgroup and Depot Springs Subgroup with respect to selected lithostratigraphic units of the Adelaide Geosyncline. Note the stratigraphic position of dolostones within the Umberatana and Wilpena Groups.

disconformity by a thin (2–5 m), massive, purple, coarse-grained to pebbly cross-bedded sandstone of fluvial origin (Plummer 1978). In places, it is interbedded with conglomerate and purple shale. It is, in turn, overlain by greyish red shale and thin, interbedded lenticular sandstone of the Bunyerroo Formation with a sharp, conformable contact. Dyson (1992b, 1995¹) recognised the regional significance of this unconformity and the nature of the channel-fill facies overlying the unconformity. The channel-fill facies is referred to herein as the Wilcolu Sandstone and is conformably overlain by shale of the Bunyerroo Formation.

The Wilcolu Sandstone and Bunyerroo Formation together constitute the Aruhna Subgroup (Fig. 2). It is a third-order cycle that is overall transgressive and was deposited during one eustatic fall and rise of relative sea level. A reference section is designated in Bunyerroo Valley between Aroona Ruins and Wilcolu Creek on PARACHILNA. The Aruhna Subgroup was studied at Bunyerroo Gorge, Mount Terrible, Partacoona, Pettana Gorge, Trebilcock Gap and the Mount Goddard and Angepena Synclines (Fig. 3). A type section for the Wilcolu Sandstone (Fig. 4) is

designated in Wilcolu Creek, 2 km south of Bunyerroo Gorge (lat. 31° 25' 10" S, long. 138° 13' 12" E).

Lower sequence boundary

The Wilcolu Sandstone represents an incised valley fill near the top of the ABC Range Quartzite. A shallow palaeovalley can be traced from the Aroona Valley (30 m thick) to south of Bunyerroo Gorge where it attains a thickness of 3 m (Fig. 4). The base of the incised valley fill is interpreted to be a sequence boundary that was cut during a lowstand of relative sea level. At Partacoona (Fig. 3), the base of the incised valley is interpreted as a combined sequence boundary/transgressive surface. A possible sequence boundary exists near the top of the ABC Range Quartzite at Hidden Gorge (Fig. 3). Here, the sequence boundary is overlain by a thick (> 10 m), very coarse-grained sandstone or conglomerate that is typically bimodal and very well-sorted. Internally, diagenetic chert occurs as replacements and overgrowths. The same texture is observed in the Wilcolu Sandstone near Bunyerroo Gorge.

MORALANA SUPERGROUP		HAWKER GROUP		EARLY CAMBRIAN	
NEOPROTEROZOIC	HEYSEN SUPERGROUP	WILPENNA GROUP	POUND SUBGROUP		MARINOAN
			ARUHNA SUBGROUP	Wanoka Formation	
				Wearing Dolomite	
				Burr Well Mbr.	
			ARUHNA SUBGROUP	Bunyeroo Formation	
				Wilcolu Sandstone	
				ABC Range Quartzite	
			SANDISON SUBGROUP	Brachina Formation	
				Boyley Range Siltst. Mbr.	
				Moorillah Siltst. Mbr.	
			SANDISON SUBGROUP	Moolooloo Siltst. Mbr.	
				Nuccaleena Formation	
				Reynella Siltst. Mbr.	
			UN-NAMED SUBGROUP	Elatina Formation	
	UN-NAMED SUBGROUP	Trezona Formation			
		Enorama Shale			
		UN-NAMED SUBGROUP	Artipena Dolomite Mbr.		
	UN-NAMED SUBGROUP		Etina Formation		
			Tarcowie Siltstone		
		UN-NAMED SUBGROUP	Cox Sandstone Mbr.		
	UN-NAMED SUBGROUP		Tapley Hill Formation		
			Wockerawirra Dolomite Mbr.		
		UN-NAMED SUBGROUP	Sunderland Mbr.		
	UN-NAMED SUBGROUP		Mt Coernarvon Greywacke Mbr.		
			UN-NAMED SUBGROUP	Tindelpina Shale	
		UN-NAMED SUBGROUP		Wilyerpa Formation	
	UN-NAMED SUBGROUP			Warcowie Dolomite	
			UN-NAMED SUBGROUP	Holowilena Ironstone	
		UN-NAMED SUBGROUP		Pualco Tillite	
	WARRINA SUPERGROUP			BURRA GROUP	Skillogalee Dolomite
			CALLANNA GROUP		CURDIMURKA SUBGROUP
		ARKAROO LA SUBGROUP			
	ARCHAEOAN to MESOPROTEROZOIC COMPLEXES				

Fig. 2. Unconformity-bounded subgroups conforming to depositional sequences in the Umberatana Group and lower Wilpena Group (after Dyson 1995).

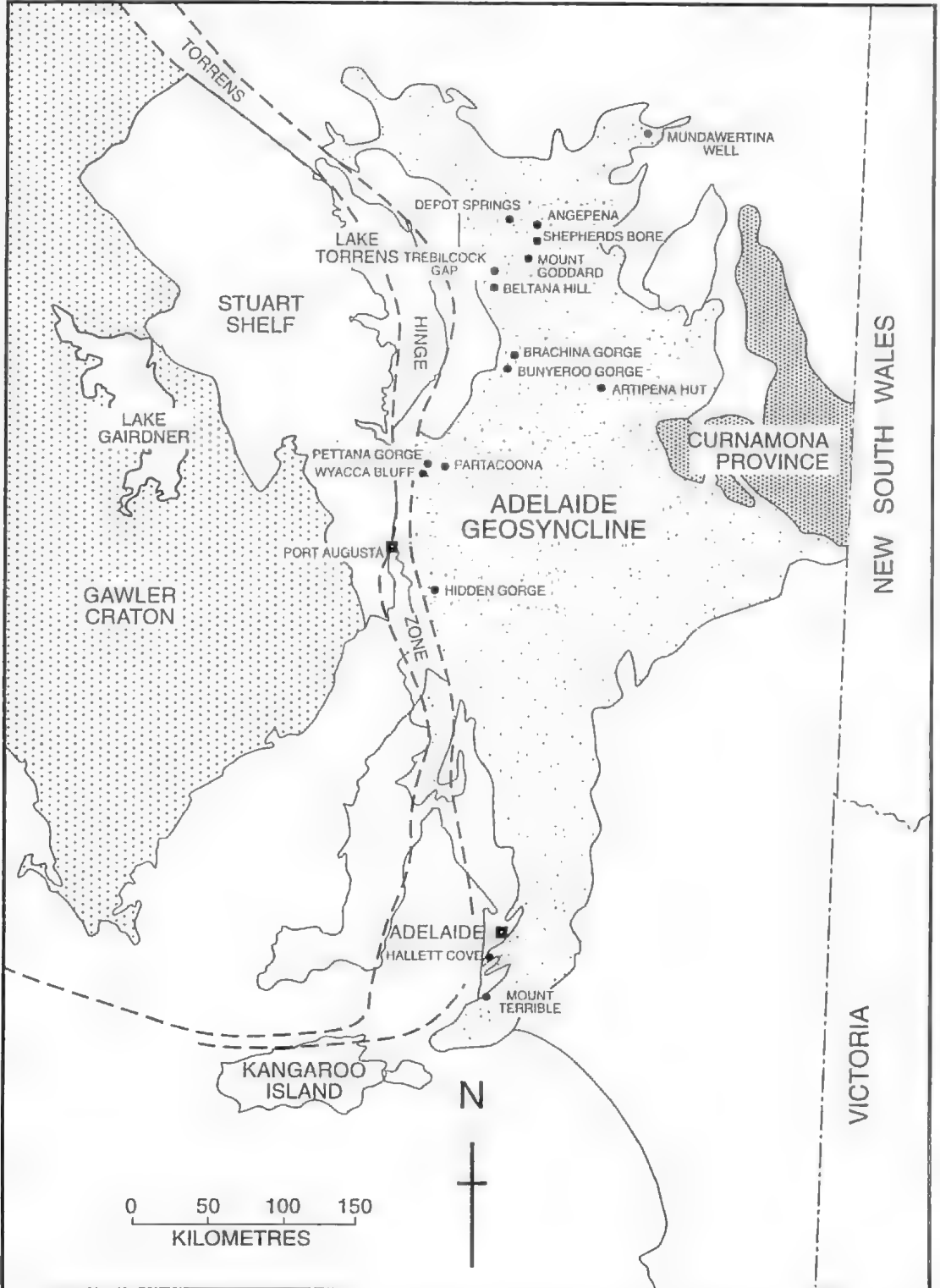
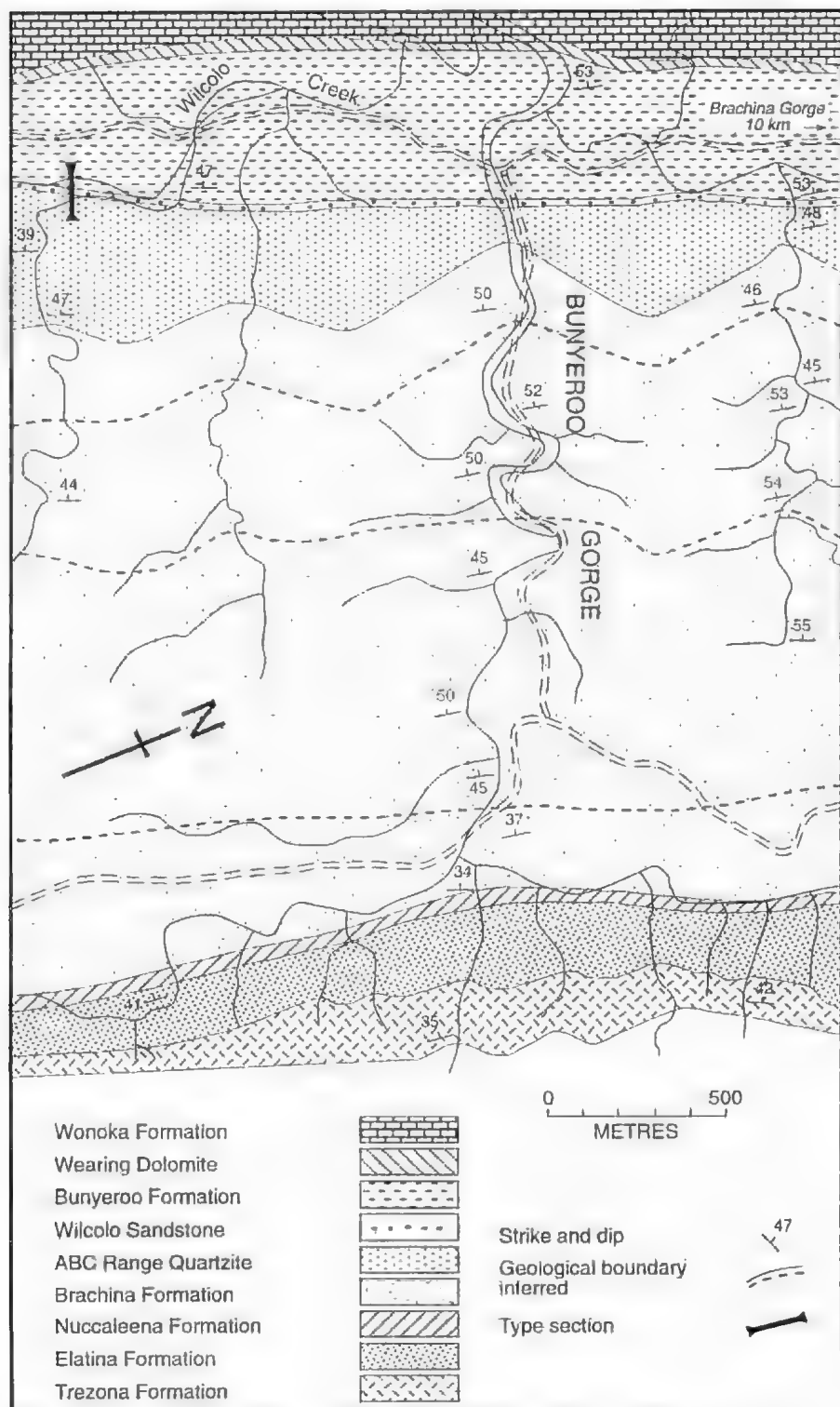


Fig. 3 Tectono-sedimentary provinces of eastern South Australia, showing localities of stratigraphic sections in the Adelaide Geosyncline and their relation to other localities on the Stuart Shelf and in the Torrens Hinge Zone (after Dyson 1995).



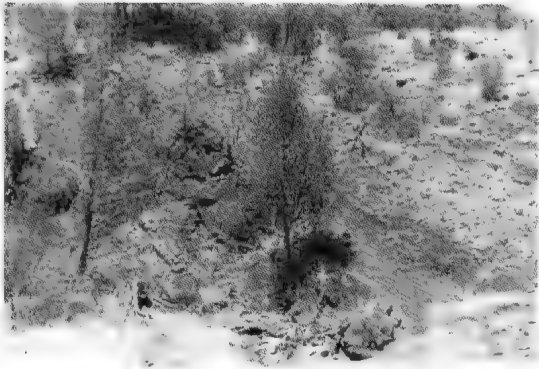


Fig. 5. Pebbly cross-bedded sandstone (2 m thick) of fluvial origin, assigned to the Wilcolo Sandstone, overlying shallow marine sediments of the ABC Range Quartzite about 2 km south of Bunyerroo Gorge. The channelised base of the sandstone is immediately left of the native pine in the centre foreground.

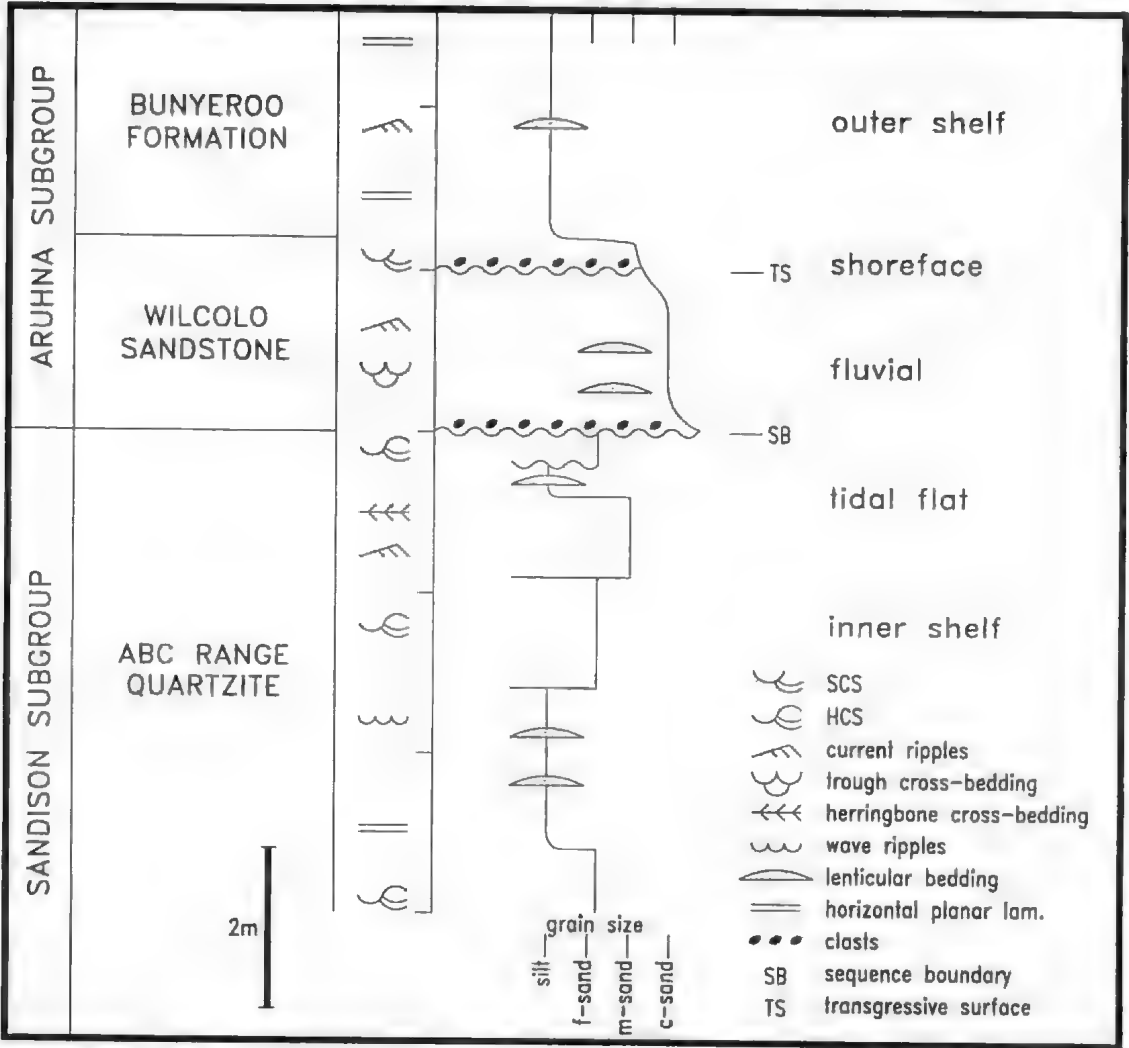


Fig. 6. Stratigraphic log of the Wilcolo Sandstone at the proposed type section, south of Bunyerroo Gorge.



Fig. 7. Fluvial channel at the base of the Wilcollo Sandstone is overlain by a 20 cm-thick mature sandstone that is in turn gradationally overlain by shale of the Bunyerroo Formation. The head of the hammer marks the sharp contact between the two sandstones, interpreted as the transgressive surface.

Wilcollo Sandstone

The fluvial channel at the base of the Wilcollo Sandstone (Fig. 5) near Bunyerroo Gorge is overlain by a thin (c. <1 m), mature sandstone (Figs 6, 7) that often displays swaley cross-stratification (SCS), hummocky cross-stratification (HCS) and symmetrical ripples (Dyson 1992b). The base of the swaley cross-stratified sandstone is interpreted as a transgressive surface. At Partacoona, an unconformity at the top of the ABC Range Quartzite is overlain by 25 m of mature, off-white quartzite that displays trough cross-bedding of tidal origin and large symmetrical wave ripples with abundant well-rounded clasts of gravel to pebble size. The quartzite was deposited in a possible incised valley of similar dimensions to that observed in the Arnoona and Bunyerroo valleys. A contact with overlying shale of the Bunyerroo Formation was not observed. Near Trebilcock Gap west of Beltana, the Wilcollo Sandstone varies in thickness from 20–50 m where it

consists of interbedded metre-thick, pebble to cobble conglomerate, medium to coarse-grained sandstone and shale. The conglomerate and sandstone display planar-tabular cross-bedding and SCS respectively, and are interpreted as having been deposited in a shoreface environment within an incised valley fill. About 1.5 km either side of Trebilcock Gap, the incised valley fill contains large (500 x 100 m) rafts of diapiric breccia, thought to have slumped into the incised valley during the early stages of deposition. On the south limb of the Mount Goddard Syncline, a greyish red, fine-grained sandstone erosively overlies the Ulupa Siltstone. The sandstone, about 1 m thick, contains angular to sub-rounded clasts of diapiric material suggesting exposure of a nearby diapir and is interpreted as being of fluvial origin (Fig. 8).

At Pettana Gorge (Fig. 3), the Wilcollo Sandstone is absent but for a thin remnant of gritty and gossanous sandstone. It is erosively overlain by a boulder conglomerate at the base of a submarine canyon in the Wonoka Formation (Dyson 1995), not mapped previously on ORROROO (Binks 1968). The base of the Wilcollo Sandstone is not exposed at Hallett Cove (Fig. 3), but at Mount Terrible it is overlain by interbedded greyish red siltstone and mature sandstone. At this locality, the base of the Wilcollo Sandstone is interpreted as a combined sequence boundary/transgressive surface. A similar situation exists at Finke Springs on the north limb of the Angepena Syncline where a thick-bedded, medium-grained, swaley cross-stratified sandstone of shoreface origin overlies the ABC Range Quartzite. On the south limb of the Angepena Syncline near Shepherd's Bore (Fig. 3), a decimetre-thick, tidally

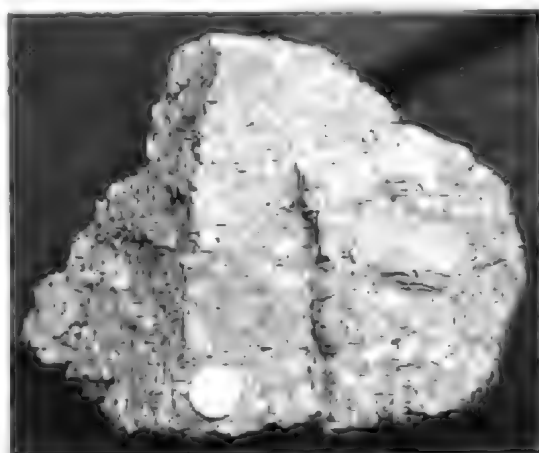


Fig. 8. Conglomerate from the Wilcollo Sandstone on the southern limb of the Mount Goddard Syncline. It contains carbonate clasts of possible diapiric origin. Coin is 28 mm in diameter.

cross-bedded sandstone erosively overlies the Ulupa Siltstone. It is overlain by a 30 m-thick section of interbedded greyish red shale and sandstone that grades upward into reddish shale of the Bunyerroo Formation.

Bunyerroo Formation

The Bunyerroo Formation (Dalgarno & Johnson 1964) is 700 m thick in its type section at Brachina Gorge (Fig. 3), where it consists of laminated to massive, dark reddish brown shale. The overall upward-fining succession is punctuated by a series of subtle, upward-coarsening cycles that in places range from 5–10 m thick. Sedimentary structures associated with very fine to fine-grained sandstone at the top of some cycles include small-scale cross-bedding and micro-HCS.

The Bunyerroo Formation was for the most part deposited below storm wave base in a middle to inner shelf setting. Dyson (1992b) placed the Bunyerroo Formation in a transgressive systems tract that was capped by the former Wearing Dolomite Member of the Wonoka Formation.

Upper sequence boundary

The sequence boundary at the top of the Bunyerroo Formation is coincident with the former Wearing Dolomite Member of Thomson (1965). It is elevated herein to formation status to reflect its regional significance. Deposition of the Wearing Dolomite is interpreted as having been contemporaneous with the canyon unconformity at the base of the Wonoka Formation (Dyson 1995¹, 1996a, b).

Depositional environment

The Wilcoco Sandstone was deposited in a fluvial and estuarine to shallow marine environment. The Bunyerroo Formation was deposited in progressively deeper water in a middle to outer shelf setting and constitutes a transgressive systems tract. Thus, sedimentation of the Aruhna Subgroup was unable to keep up with subsidence, resulting in a depositional transgression in the sense of Curran (1964). The Bunyerroo Formation thickens eastward of the Torrens Hinge Zone (Fig. 3). Adjacent to diapirs, onlapping sediments of the Aruhna Subgroup are thin. However, localised thick development of the

Bunyerroo Formation occurs adjacent to some diapirs. A thick, black succession of sulphide-rich shale adjacent to the Mucatoona Diapir (Coats 1973) suggests anoxic, deep water deposition of the Bunyerroo Formation, perhaps associated with the formation of a crestal graben over the diapir due to salt depletion. The diapirs of the Flinders Ranges often contain volcanic xenoclasts (Preiss 1987b), and Coats (1973) suggested that many diapirs on COPILEY were active and exposed during deposition of the basal Bunyerroo Formation. An inferred volcanic component of the redbeds (Mawson 1939; Plummer 1978a) may be related to depositional onlap of Bunyerroo sediments adjacent to exposed diapirs.

Dalrymple (1992) suggested that estuarine sandstones were transgressive in origin because estuaries owed their existence to marine flooding of incised valleys. On the other hand, Exxon researchers (e.g., Van Wagoner *et al.*, 1987) argued that fluvial sediments at the base of incised valleys should be assigned to the lowstand systems tract deposited during an initial fall and subsequent early rise of relative sea level. Alternatively, such fluvial units may be the updip equivalent of transgressive marine sandstones. The lack of beach deposits between the fluvial and estuarine sandstones of the Wilcoco Sandstone at Bunyerroo Gorge suggests that the base of the estuarine sandstone is the transgressive surface. The ensuing transgression eroded and reworked the former beach sediments.

Depot Springs Subgroup

The Wonoka Formation (Dalgarno & Johnson 1964) and Wearing Dolomite together represent a transgressive-regressive (T-R) cycle that is referred to as the Depot Springs Subgroup (Fig. 1). The Depot Springs Subgroup constitutes an unconformity-bounded depositional sequence and was studied at a number of localities on PARACHILNA, COPILEY and MARREE including Peltana Gorge, Wyacca Bluff, Brachina Gorge, Bunyerroo Gorge, Beltana Hill, Mount Goddard, Shepherds Bore and Mundawertina Well (Fig. 3). A reference section for the subgroup is designated in and adjacent to the Patsy Springs canyon of the Angepena Syncline near the Depot Springs H.S., 40 km east of Copley (Fig. 3).

The base of the Wonoka Formation was mapped on PARACHILNA (Dalgarno & Johnson 1966) where a colour change occurred above greyish red sandstones at the top of the underlying Bunyerroo Formation. This boundary corresponded to a rather abrupt increase in lime content. Gostin & Jenkins (1983) defined a decimetre-thick dolostone overlying reddish shales of the Bunyerroo Formation, referred

¹ HAINES, P.W. (1987) Carbonate shelf and basin sedimentation, late Proterozoic Wonoka Formation, South Australia. PhD thesis, University of Adelaide (unpub.).

² DI BONA, P.A. (1989) Geologic history – sequence stratigraphy of the late Proterozoic Wonoka Formation, northern Flinders Ranges South Australia. PhD thesis, Flinders University of South Australia (unpub.).

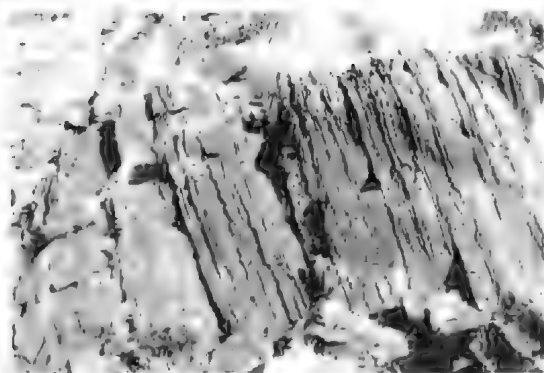


Fig. 9. Sharp contact between the Bunyeroo Formation and Wearing Dolomite in the Angepena Syncline. The Wearing Dolomite is about 30 cm thick. Its base is marked by the head of the hammer with sedimentary facies lying to the right.



Fig. 10. Wearing Dolomite displaying micro-HCS, Angepena Syncline.

to informally as the Wearing Dolomite Member (Thomson 1965), as the base of the Wonoka Formation. Jenkins (1993) defined the base of the Wonoka Formation in Bunyeroo Gorge at the base of an intraformational conglomerate within the Wearing Dolomite Member. Haines (1987²) divided the Wonoka into 11 lithofacies units. These units were subsequently adopted by other workers (e.g., Di Bona 1989; Christie-Blick *et al.* 1990) with the prefix W.

Lower sequence boundary

The base of the Wearing Dolomite is defined as a sequence boundary. It can be either sharp or diffuse in nature. Jenkins (1993) interpreted a sequence boundary at the base of an intraformational conglomerate within the Wearing Dolomite. However, the intraformational conglomerate displays edgewise clasts that have in the past been interpreted as storm rosettes (e.g., Dyson & von der Borch 1986). Dyson (1992b) suggested that the Wearing Dolomite represented deposition within a condensed section that included a possible maximum flooding surface. Furthermore, the Wearing Dolomite was deposited on a sediment-starved hiatal surface below storm wave base (see below).

Wearing Dolomite

The former Wearing Dolomite Member of Thomson (1965) is a thin cream, dolostone or dolomitic siltstone that has been mapped over extensive areas of the Flinders Ranges (Forbes & Preiss 1987). It corresponds to unit 1 of Haines (1987²). The Wearing Dolomite often sharply overlies the Bunyeroo Formation with apparent

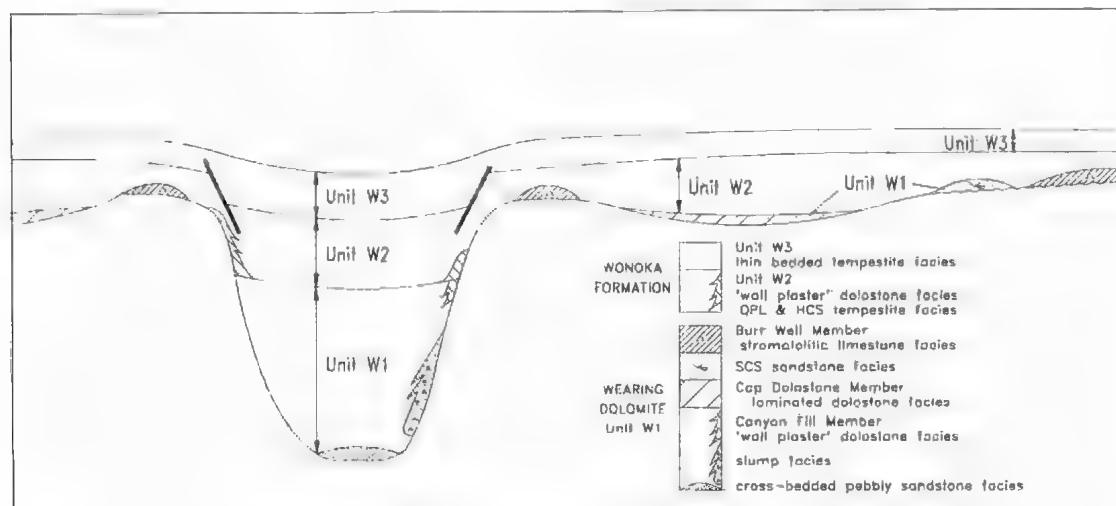


Fig. 11. Schematic cross-section through the Patsy Springs Canyon in the Angepena Syncline (after Dyson 1995¹). Note the relationship between dolostones of the Wearing Dolomite.

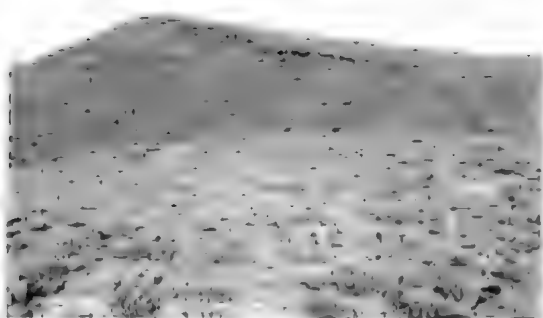


Fig. 12. Brecciated limestone of the Wearing Dolomite unconformably overlying the Bunyeruo Formation east of Beltana Hill.

conformity (Fig. 9). It is characterised by wavy to parallel lamination and, less commonly, by micro-HCS (Fig. 10). A similar situation exists on the south limb of the Angepena Syncline and north limb of the Mount Goddard Syncline. Near Mundawertina Well and on the northern limb of the Angepena Syncline, the Wearing Dolomite splits into two thin dolostones that are separated by up to 25 m of laminated grey green shale. At Pettana Gorge (Fig. 3), a 2 m-thick boulder conglomerate cuts downward into the ABC Range Quartzite. It marks the base of a shallow canyon with an estimated relief of 70 m. About 5 km south of Pettana Gorge near Wyacca Bluff, the Bunyeruo Formation attains a thickness of about 50 m where it is sharply overlain by a decimetre-thick dolostone of the Wearing Dolomite with a sharp, planar contact. It is interpreted as the correlative conformity adjacent to the submarine canyon.

Other dolostones are also genetically related to the Wearing Dolomite at this stratigraphic level (Fig. 11). About 2 km east of Beltana Hill (Fig. 3), the Wearing Dolomite passes laterally into a several metre-thick, cream to orange laminated dolostone that is often brecciated and present as detached slump blocks (Leeson & Nixon 1966). Here, it overlies reddish shales of the Bunyeruo Formation with an angular unconformity (Fig. 12). This dolostone is thought to represent the "wall plaster veneer" of Hickoff (1988¹). A similar relationship can also be observed near Mundawertina Well, and also on the south limb of the Angepena Syncline where the Wearing Dolomite can be traced into slumped wall plaster at the edge of the Patsy Springs

canyon (Dyson 1995¹). On the south limb of the Mount Goddard Syncline, the Burr Well Member of Di Bona (1989¹) consists of mature, medium-grained, swaley cross-stratified, carbonate-cemented sandstone or intraformational conglomerate with edgewise elasts of dolostone, and passes laterally into stromatolitic dolostone (see Fig. 11). A basal lag comprises diapiric detritus. Where the Wearing Dolomite displays such unconformity, it is defined as the Burr Well Member in the sense of Di Bona (1989¹).

The base of the Wearing Dolomite is interpreted to be a deep water sequence boundary. A maximum flooding surface at the top of the Bunyeruo Formation may coincide with this sequence boundary. The diffuse base of the Wearing Dolomite suggests that early post-depositional dolomitization took place on a sediment-starved hiatal surface. Wavy to parallel lamination and micro-HCS further suggests deposition below storm wave base (e.g., Dyson 1995). The Wearing Dolomite can be traced into the Burr Well Member on the south limb of the Mount Goddard Syncline. The Burr Well Member was deposited in a storm-dominated shoreface to tide-dominated, lagoonal environment. Its sharp, erosional base is a combined sequence boundary/transgressive surface. The "wall plaster veneer" was deposited on the canyon shoulders. It is interpreted to be coeval with deposition of the Wearing Dolomite and unit W2 of the Wonoka Formation (Fig. 11).

The Wearing Dolomite, together with the Wonoka Formation, is present on the Stuart Shelf where it can be observed in drillcore (e.g., Bopeechee 2 at 367.2 m). A possible Wearing equivalent, only a few centimetres thick, crops out south of Bill's Lookout near the north-western side of Lake Torrens within what was previously interpreted as Yarloo Shale (Johns *et al.* 1966). This suggests that the Wearing Dolomite transgressed the Stuart Shelf prior to deposition of the Wonoka Formation.

Wonoka Formation

The Wearing Dolomite is overlain by unit W2 of the Wonoka Formation, consisting of greyish red, fine-grained sandstone and interbedded calcareous shale. It grades upward into the dominantly calcareous shale of unit W3. The succession represented by units W2 and W3 is overall transgressive. A colour change to greenish limestones in the middle section of unit W3 marks the base of regressive sedimentation in the Wonoka Formation (Fig. 11).

The lithofacies units W3-7 inclusive of the Wonoka Formation display an overall upward sanding trend. It culminates in a thick, storm-dominated, mixed

¹ Hickoff, K.H. (1988) Geological history and origin of the late Proterozoic Barossa Hill Canyon Complex, Adelaide Geosyncline, S.A. PhD thesis, Flinders University of South Australia (unpubl.).

carbonate/siliciclastic succession, commonly displaying HCS (Haines 1988) that was deposited in an inner to middle shelf setting. Units W3-7 of the Wonoka Formation, as interpreted by Haines and other workers, represent regressive sedimentation from initial deposition below storm wave base to deposition above fairweather wave base.

A number of metre-thick, greyish red, medium-grained sandstone beds in unit W7 that are characterised by SCS may represent forced regressive deposits associated with a falling stage systems tract (e.g., Dyson 1996c). In the Angepena Syncline, a disconformity at this stratigraphic level is overlain by a several metre-thick medium-grained sandstone that in many places displays horizontal-planar lamination and SCS. It is interpreted to represent deposition on the lower shoreface in a marine environment. Di Bona & von der Borch (1993) interpreted a lowstand delta at this level in the Umberatana Syncline. Unit W7 is overlain by a succession of shallow marine sandstone and carbonate of tidal and lagoonal origin (Haines 1990) that corresponds to units W8-11. Occasionally, these units can be observed to grade upward into the red shale and sandstone of the Bonney Sandstone, e.g., near Mount Goddard.

The T-R cycle of the Depot Springs Subgroup is an unconformity-bounded, third-order depositional sequence. The canyon fill, represented by units W1, W2 and to a lesser extent W3, constitute the transgressive cycle of the Depot Springs Subgroup. Deposition of unit W1 in the canyon fill was contemporaneous with deposition of the Wearing Dolomite on a sediment-starved hiatal surface. A possible condensed section is represented by unit W3. The middle of this unit corresponds to an abrupt colour change and increase in lime content. A maximum flooding surface may be contained within unit W3 and is therefore equated with a downlap surface. It is overlain by the regressive lithofacies of the Wonoka Formation.

Submarine canyons

The Wearing Dolomite was developed adjacent to a major submarine unconformity on a sediment-starved hiatal surface that corresponds to a combined sequence boundary and major flooding surface (Dyson 1995¹). It can be observed to pass laterally into slump breccias on the shoulders of submarine canyons, e.g., near Beltana Hill, south limb of Angepena Syncline. On the north limb of the Angepena Syncline, the Wearing Dolomite consists of two dolostones that are separated by some 20 m of shale. The upper dolostone overlies the truncated edge of a lower dolostone, suggesting canyon erosion occurred before deposition of the upper

dolostone. Furthermore, unit W2 overlies the fill of the Patsy Springs canyon in the Angepena Syncline. Retrogressive slumping on the outer shelf was the precursor to canyon incision, and proceeded up to the level of unit W3 in the Wonoka Formation which marks the turn around from transgressive to regressive sedimentation in the Wonoka Formation (Fig. 11). This interpretation questions the timing of earliest canyon incision expounded by other workers that coincided with deposition of units W3, W4 or W5 (e.g., Haines 1987; Di Bona 1989; Christie-Blick *et al.* 1990, 1995).

Upper sequence boundary

The Bonney Sandstone often displays a sharp though apparently conformable contact with the underlying Wonoka Formation. However, the relationship becomes disconformable in the vicinity of diapirs. Adjacent to some diapirs, e.g., Pinda Diapir on COPLEY and Frome Diapir on PARACHILNA, the Bonney Sandstone displays an unconformable relationship with the Wonoka Formation (Dyson unpub.). Thus, the base of the Bonney Sandstone of the Pound Subgroup is interpreted as a sequence boundary. Dyson (1995¹, 1996a, unpub.) suggested that the development of several prominent unconformities or sequence boundaries within the Umberatana and Wilpena Groups was associated with periods of active and passive diapirism, which in turn was related to major extensional events during break-up of the Neoproterozoic supercontinent.

Discussion

The use of subgroup as an unconformity-bounded unit

The previous use of subgroup in a litho-stratigraphic sense has caused problems in regional mapping programmes. A good example is the differentiation of interglacial deposits in the Umberatana Group. They embrace the Farina Subgroup (Coats *et al.* 1969; Thompson 1969) and the Willochra Subgroup (Thompson 1969). The intention of the term Farina Subgroup was to include all relatively deeper water sediments, in contradistinction from the dominantly shallow water redbeds of the Willochra Subgroup (Coats & Preiss 1987). There has been inconsistency in application of the terms, especially in some transitional regions where facies intertongue or are intercalated (Coats & Preiss 1987). The southern portion of PARACHILNA is such a region where a basis for this distinction is warranted. Therefore, a revised stratigraphic nomenclature of the interglacial deposits could be based on differentiation of subgroups as a genetic unit in terms of sequence stratigraphy.

A sequence stratigraphic framework for the Umberatana and Wilpena groups is shown in Fig. 2 and is based on differentiation of subgroups as a genetic unit. An unconformity-bounded sequence incorporates the Tindelpina Shale and Tapley Hill Formation. Similarly, an unconformity-bounded sequence is defined by the top of the Tapley Hill Formation to near the top of the Etina Formation, and an overlying sequence is capped by an unconformity at the base of the Etina Formation. The Willochra Subgroup previously included the Mannoo glaciols of the Etina Formation (Thomson 1969). The Etina Formation is capped by dolostone of the Nuccaleena Formation, the basal unit of the Sandison Subgroup. The Sandison Subgroup is unconformably overlain by the Aruhna Subgroup that comprises the Wilcollo Sandstone and Bunyerroo Formation. The Aruhna Subgroup is in turn unconformably overlain by the Wearing Dolomite at the base of the Depot Springs Subgroup (Fig. 2). A similar scheme was proposed for the Kanmantoo Group of Cambrian age (Dyson 1995). More work is required to differentiate genetic units within the Pound Subgroup which contains possibly two unconformity-bounded sequences, with sequence boundaries at the base of the Bonney Sandstone and Ediacara Member of the Rawnsley Quartzite (e.g., Dyson, 1995).

Lithostratigraphic, biostratigraphic and chronostratigraphic units will continue to be used as the basis for most stratigraphic studies. However, the use of unconformity-bounded units is invaluable in basins where the development of stratigraphic units was controlled by tectonic episodes and eustatic sea level cycles. In such basins, e.g., the Adelaide Geosyncline, unconformities pass laterally into correlative conformities where traditional stratigraphy is unlikely to differentiate the lateral and vertical extent of genetic units above and below the sequence boundary. Thus, the use of unconformity-bounded units can contribute to the understanding of the stratigraphy and geologic history of a basin, it can provide the framework for regional stratigraphic framework and it can enable the mapping and expression of stratigraphic concepts for which other stratigraphic units are inadequate (Salvador 1994).

A hierarchy of unconformity-bounded units can be formulated by determining sequence order in a basin. Mitchum & Van Wagoner (1991) proposed a sequence boundary hierarchy of five orders on the frequency of boundary occurrence. Alternatively, Embry (1993) suggested five orders of sequence boundaries based on the nature of the boundary. The latter method is possibly less subjective. However, if every pair of unconformities is used to recognise and name an unconformity-bounded unit such as in the case of the Cardium Formation in the Cretaceous

Western Interior Seaway of Canada (Walker 1990), the stratigraphic units would grow unmanageably (Salvador 1994). The use of the subgroup as a depositional sequence of third-order cyclicity thereby usefully limits the establishment of meaningful and useful stratigraphic units on a regional and inter-regional basis.

The significance of dolostones capping Adelaidean sequences

The Wearing Dolomite of the Depot Springs Subgroup was developed adjacent to a major submarine unconformity on a sediment-starved hiatal surface that corresponds to a combined sequence boundary and major flooding surface. There are other dolostones or units containing significant amounts of dolostone that are associated with sequence boundaries in the Umberatana and Wilpena Groups (Fig. 2). They are the Warcovie Dolomite, the

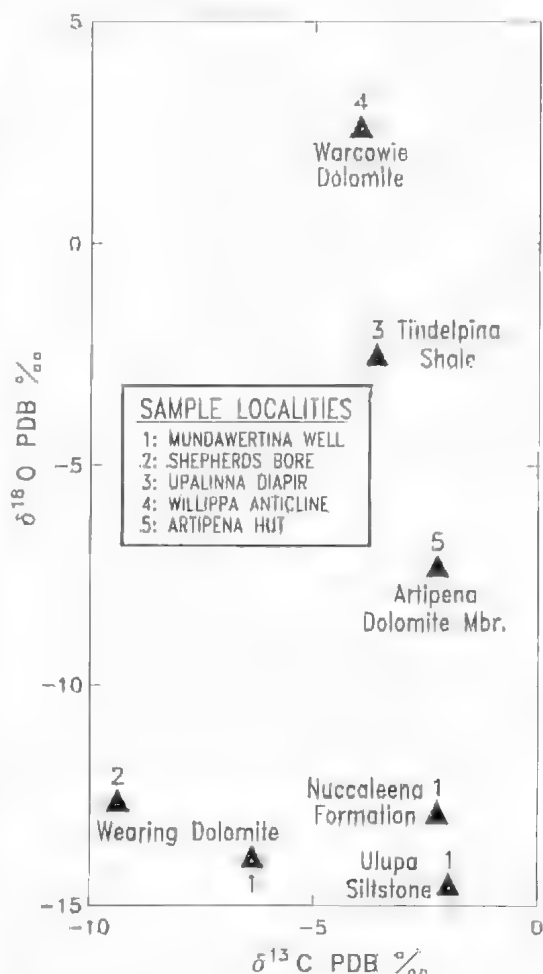


Fig. 13. Isotopic data for Adelaidean dolostones (based on Dyson 1995).

Tindelpina Shale and the Nuccaleena Formation, all of which cap sequences of glaciogenic origin. They are commonly referred to as cap dolostones (e.g., Williams 1979). Another dolostone occurs within the lower Enorama Shale and is prominent on south-east PARACHILNA, e.g., between the Willippa Anticline and Martins Well Dome. It is formally referred to here as the Artipena Dolomite Member of the Enorama Shale and a type section is designated 2 km south of Artipena Hut (Fig. 3). Here, it consists of two thin (10–50 cm) dolostones that are separated by 3 m of greyish red shale, and marks the transition from transgressive to overlying regressive sedimentation of the Enorama Shale.

These dolostones of the Umberatana and Wilpena groups display similar characteristics and are interpreted to have been deposited on major flooding surfaces under cold water conditions. Their isotopic data, based on Dyson (1995¹) in Fig. 13, display two apparent trends. The carbon isotope values show a shift to more negative values with possible increase in water depth, accompanied by an increase in diagenesis. This suggests that the Wearing Dolomite was deposited in greater water depths than the other dolostones, and was most susceptible to secondary, post-depositional alteration. The oxygen isotope values show a shift to more negative $\delta^{18}\text{O}$ above the stratigraphic level of the Warcowie Dolomite. If $\delta^{18}\text{O}$ is sensitive to temperature changes, then it might show a similar trend to relative water depth as suggested by $\delta^{13}\text{C}$ (e.g., Baum *et al.* 1994). However, the shift to more negative $\delta^{18}\text{O}$ above the Warcowie Dolomite is interpreted to reflect the overall increase in palaeotemperature following the Sturtian glaciation. This interpretation must be viewed with caution, particularly with respect to the Wearing Dolomite, because of overprints associated with secondary, post-depositional alteration. Deposition of the Warcowie Dolomite in a glaciogenic environment is suggested by the presence of dropstones (Dyson 1995¹, 1996b). Palaeotemperatures for the Neoproterozoic dolostones are thought to range from 5° C for the Nuccaleena Formation and Wearing Dolomite, to -5° C for the Warcowie Dolomite (C.P. Rao pers. comm. 1995).

Each of the dolostones was deposited on a maximum flooding surface associated with terrigenous starvation. The Milendella Limestone, a carbonate of Cambrian age, occupies a similar stratigraphic position in the Kamburubi Group. Incised valleys are associated with the Milendella Limestone and Seachiff Sandstone (Dyson & von der

Borch 1994; Dyson 1996d). Prograding slope complexes are associated with the Tindelpina Shale. Such units are considered to be the downslope equivalents of incised valleys (Mitchum *et al.* 1993). A pertinent question is why dolostones of the Wearing Dolomite and Warcowie Dolomite do not appear to be associated with incised valleys that show dominantly shallow water features. Major extensional events coinciding with deposition of these units, together with high rates of subsidence, resulted in no fall in relative sea level and precluded development of sandy highstand facies. Instead, dolostones cap relatively deep water sediments of the Bunyeroo Formation and Holowilena Ironstone respectively. Each dolostone is developed on an hiatal surface that represented a period of terrigenous starvation. In each case, this surface can be followed into the submarine unconformity where a major canyon was possibly cut on the outer shelf. In such a setting, a flexural response of the continental margin may have occurred as an isostatic readjustment to canyon erosion (McGinnis *et al.* 1993). For a wide continental shelf, flexural uplift of the outer shelf would not have influenced the position of the shoreline, resulting in an erosional unconformity developed only across the distal shelf (McGinnis *et al.* 1993). The hiatus generated would be greatest across the distal shelf and decrease in a landward direction. Incised valley fills of the Seachiff Sandstone and Milendella Limestone are overall transgressive but display relatively shallow water features at their base. Sequence boundaries at the base of these incised valleys were formed during lesser extensional events when the degree of subsidence was relatively small or, more likely, when the width of the palaeoshelf was relatively narrow. Thus, a fall in relative sea level on the outer shelf resulted in subaerial incised valleys comprising basal fluvial to estuarine deposits.

Acknowledgments

This paper is based on field studies undertaken during postgraduate research at Flinders University under the supervision of Professor Chris von der Borch. Several useful comments were suggested by reviewers Chris Nedin and Wolfgang Preiss. Aspects of the current study were discussed with Peter Reid and Wolfgang Preiss. Gail Jackson and Gihazi Kraishnan kindly drafted the figures.

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STRATIGRAPHY OF THE NEOPROTEROZOIC TENT HILL FORMATION AND SIMMENS QUARTZITE AT SOUTH TENT HILL ON THE STUART SHELF, SOUTH AUSTRALIA

*By IAN A. DYSON**

Summary

Dyson, I. A. (1996) Stratigraphy of the Neoproterozoic Tent Hill Formation and Simmens Quartzite at South Tent Hill on the Stuart Shelf, South Australia. *Trans. R. Soc. S. Aust.* 120(3), 117-129, 29 November, 1996.

The Tent Hill Formation and Simmens Quartzite represent regressive, shallow marine sedimentation of the Sandison Subgroup on the Stuart Shelf. At South Tent Hill, the Tent Hill Formation comprises the Tregolana Shale, Lincoln Gap Siltstone and Corraberra Sandstone members and represents deposition in a storm-dominated shelf environment. Sharp-based, swaley cross-stratified sandstone beds of the Corraberra Sandstone Member are interpreted as forced regressive deposits formed above fairweather wave base. The overlying Simmens Quartzite was deposited on a broad, open shelf that was conducive to tidal amplification. These units are correlated with their stratigraphic equivalents in the Adelaide Geosyncline.

Key Words: Stratigraphy, Neoproterozoic, Tent Hill Formation, Simmens Quartzite, Lincoln Gap Siltstone Member, Sandison Subgroup, Stuart Shelf, Adelaide Geosyncline.

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Introduction

On the Stuart Shelf, the flat lying sediments of the Tent Hill Formation crop out west of the Torrens Hinge Zone and Adelaide Geosyncline in South Australia. The Tent Hill Formation (Brown 1885) was named after the flat-topped hills 25 km northwest of Port Augusta (Fig. 1). As part of a major study (Dyson 1995¹), the sedimentology and stratigraphy of the Tent Hill Formation and Simmens Quartzite were investigated in the type section at South Tent Hill (Fig. 2) and represent the first detailed synthesis of the sedimentology and stratigraphy of these formations. This paper revises the stratigraphic nomenclature for the Tent Hill Formation on the Stuart Shelf.

At South Tent Hill, the Tent Hill Formation was formally defined as consisting of three members, namely the Tregolana Shale Member, the Corraberra Sandstone Member and the Simmens Quartzite Member (Dalgarno *et al.* 1968). This study has elevated the Simmens Quartzite Member to formation status and redefined the Corraberra Sandstone Member, thereby incorporating the Lincoln Gap Siltstone Member into the Tent Hill Formation (Fig. 3). The Tent Hill Formation is correlative with the Brachina Formation in the Adelaide Geosyncline. Similarly, the overlying Simmens Quartzite may be correlated with the ABC Range Quartzite. The name "Lincoln Gap Siltstone

Member" has been reserved by the Central Register of Australian Stratigraphic Names.

Previous work

The section at South Tent Hill (Fig. 4), originally described by Thomson (1965), was proposed by Dalgarno *et al.* (1968) as the type section for the Tent Hill Formation. The underlying formation was referred to as the "Tregolana shales" by Miles (1955). The term "Lincoln Gap Flagstones" was proposed by Miles (1955) for the sandy succession of the Tent Hill Formation. Crawford (1964) referred to the lower part of this unit as the Corraberra Sandstone. Thomson (1965) defined the Corraberra Sandstone Member and the Simmens Quartzite Member as constituents of the Tent Hill Formation. Coats (1965) correlated the Tregolana Shale Member and Corraberra Sandstone Member with the Brachina Formation, and the Simmens Quartzite Member with the ABC Range Quartzite. Johns (1968) proposed the terms "Woomera Shale Member" and "Arcoona Quartzite Member" on the northern Stuart Shelf where they were considered lateral equivalents of the Tregolana Shale and Simmens Quartzite Members, respectively (Coats 1965).

The stratigraphy of the Tent Hill Formation was reviewed by Coats (1965), Thomson (1965), Johns (1968) and Forbes & Preiss (1987). It was considered to be of Marinoan age by Thomson (1965). However, the sedimentology of the Tent Hill Formation has never been studied in detail and the stratigraphic column of the South Tent Hill section by Thomson (1965) is the only previous attempt to identify and document the sedimentary structures. Johns (1968) considered that the suite of sedimentary structures in

*National Centre for Petroleum Geology and Geophysics, University of Adelaide Adelaide S. Aust 5005.

¹Dyson, I.A. (1995) Sedimentology and stratigraphy of the Neoproterozoic Sandison Subgroup: a storm-dominated shallow marine sequence in the Adelaide Geosyncline, South Australia. PhD Thesis, Flinders University of South Australia (unpubl.)

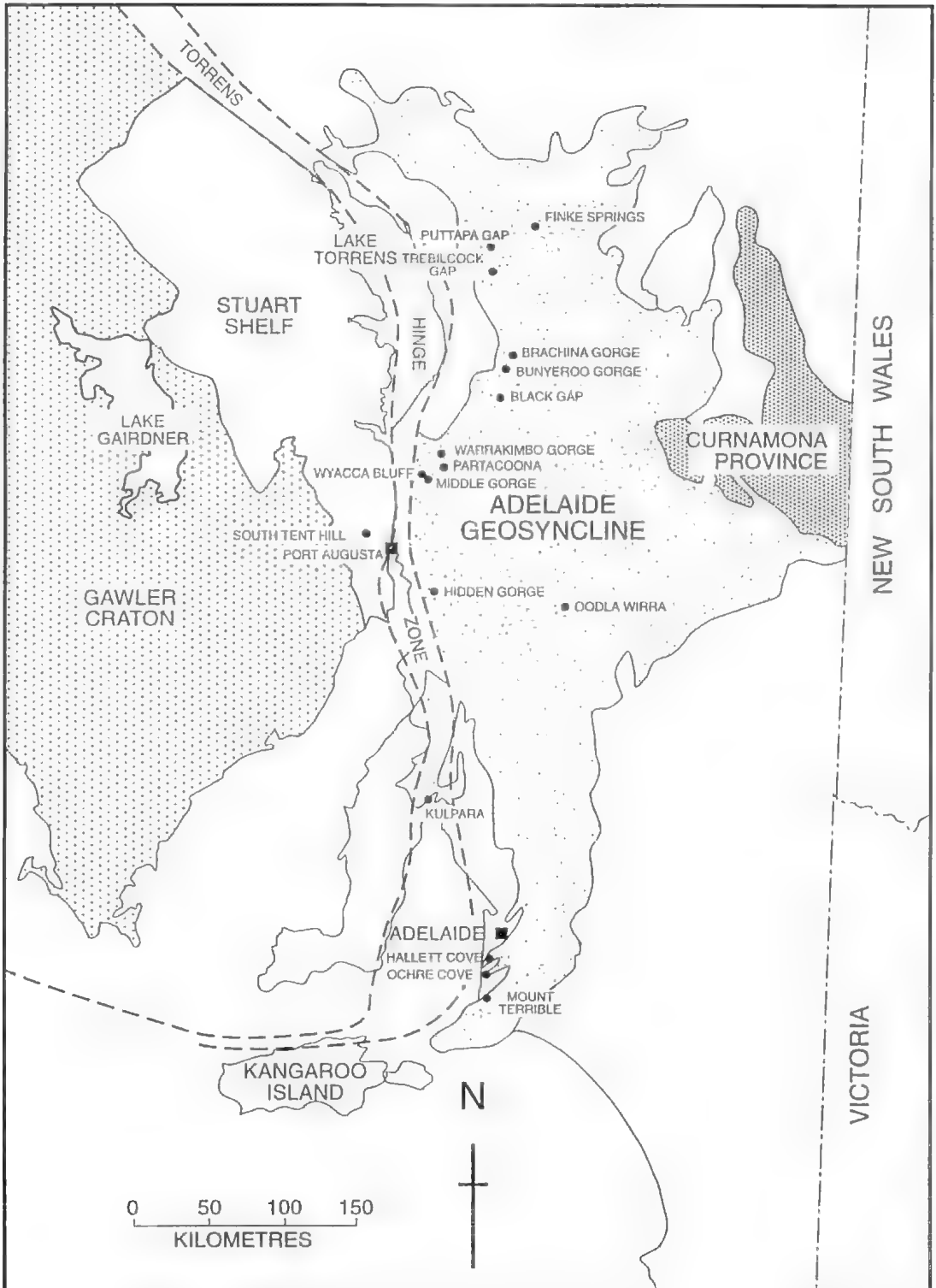
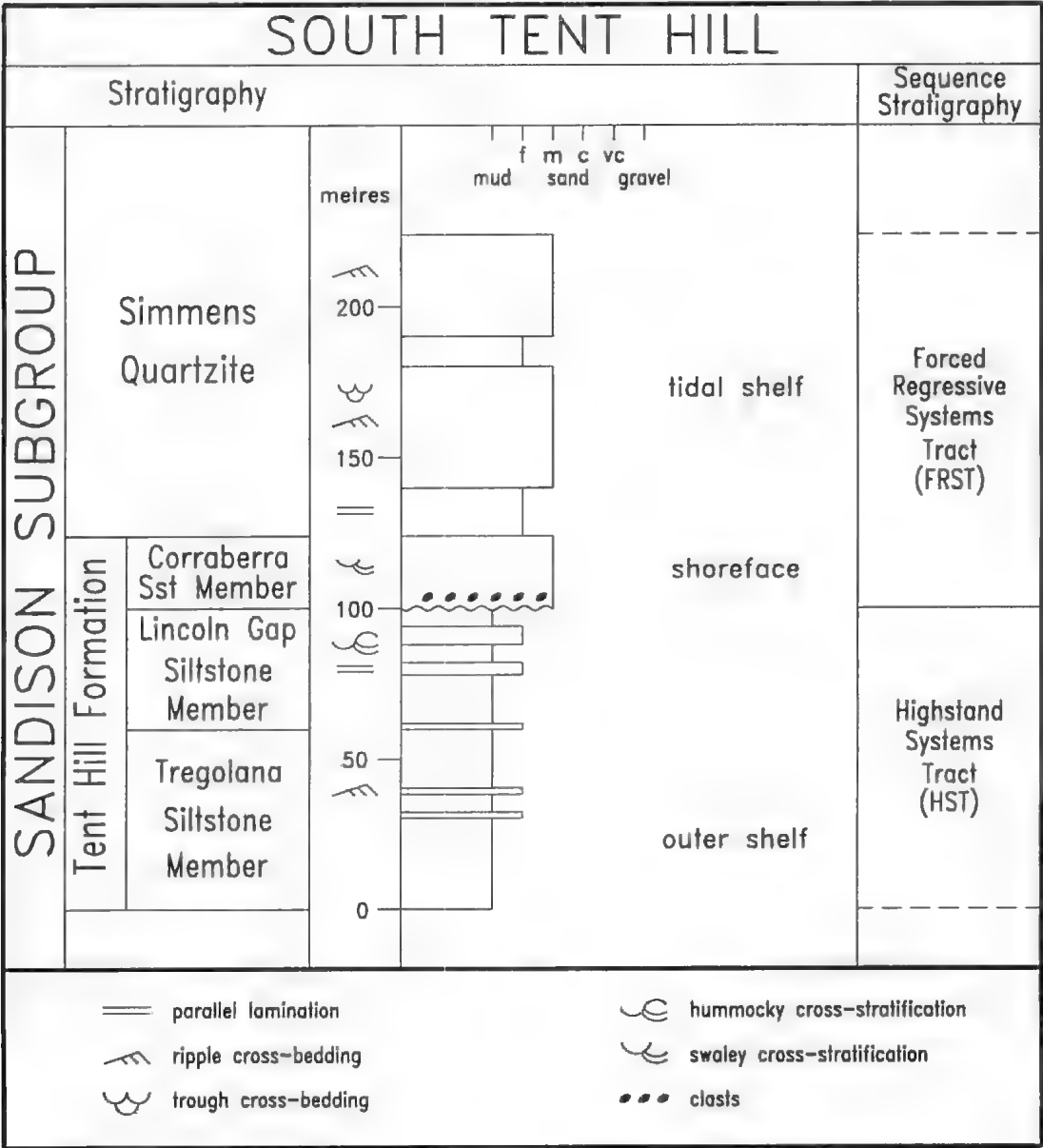


Fig. 1. Tectono-sedimentary provinces in South Australia, showing localities of stratigraphic sections in the Adelaide Geosyncline and their relation to other localities on the Stuart Shelf and in the Torrens Hinge Zone (after Dyson 1995¹).



Fig. 2. View of the type section for the Tent Hill Formation (Dalgarno *et al.* 1968) on the southern face of South Tent Hill.

Fig. 3. Stratigraphic log of the Simmens Quartzite and Tent Hill Formation at South Tent Hill (after Dyson 1995).



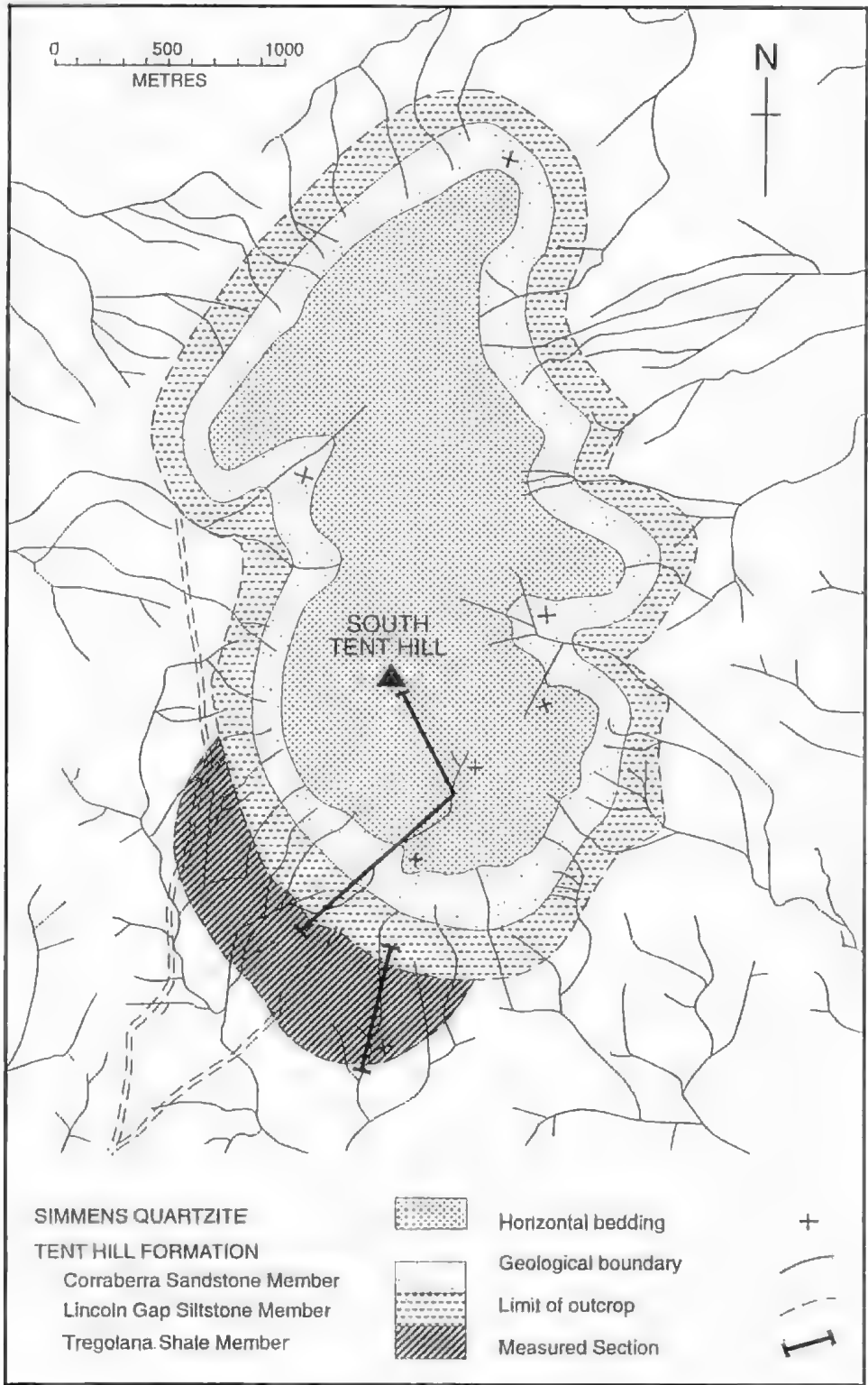


Fig. 4. Geological map of South Tent Hill

the Tent Hill Formation was indicative of strong current action and shallow water sedimentation.

Stratigraphy

The former Simmens Quartzite Member of the Tent Hill Formation is raised herein to formation status to reflect its regional significance. Together, the Tent Hill Formation and Simmens Quartzite (Fig. 3) represent regressive sedimentation of the Sandison Subgroup on the Stuart Shelf. The Sandison Subgroup is an unconformity-bounded depositional sequence in the sense of Mitchum (1977). Dolostone of the underlying Nuccaleena Formation does not crop out in the Tent Hills but is present in drillcore from the Stuart Shelf. It is commonly about 2-6 m thick and displays a sharp to gradational base. The Nuccaleena Formation was deposited below storm wave base on a combined sequence boundary/transgressive surface that represents an hiatus surface of tectrogenous starvation. The lower Tent Hill Formation comprises the Tregolana Shale and Lincoln Gap Siltstone members that represent the highstand systems tract of the Sandison Subgroup. An interpreted falling stage or forced regressive systems tract (Dyson 1996a), comprising the overlying Corraberra Sandstone Member of the Tent Hill Formation and the Simmens Quartzite, is placed

between the highstand systems tract and the sequence boundary at the top of the Sandison Subgroup (Fig. 3).

The Sandison Subgroup on the Stuart Shelf and in the Adelaide Geosyncline (Fig. 5) is unconformably overlain by the Wilcollo Sandstone and, together with the Yarlou Shale, is herein assigned to the Aruhna Subgroup (Dyson 1996b). The Yarlou Shale is in turn unconformably overlain by the Wearing Dolomite and, together with the Wonoka Formation, is assigned to the Depot Springs Subgroup (Dyson 1996b).

Tent Hill Formation

The Tent Hill Formation, about 200 m thick at South Tent Hill, is an upward-sanding unit consisting of the Tregolana Shale Member, the Lincoln Gap Siltstone Member and the Corraberra Sandstone Member (Fig. 3). It is gradationally overlain by the Simmens Quartzite.

Tregolana Shale Member

The Tregolana Shale Member consists of laminated to thin-bedded, very fine to fine-grained, dark greyish brown sandstone interbedded with greyish red shale (Fig. 6). It is about 60 m thick.

REGION	STUART SHELF	FLEURIEU ARC	TORRENS HINGE ZONE	SOUTH WEST FLINDERS RANGES	NACKARA ARC	CENTRAL FLINDERS RANGES	NORTH FLINDERS RANGES
TYPE AREA	South Tent Hill	Hallett Cove	Kulpara	Hidden Gorge	Oodla Wirra	Bunyerroo Gorge	Finke Springs
WILPENA GROUP	DEPOT SPRINGS SUBGROUP	hiatus	hiatus	hiatus	Wonoka Formation	Wonoka Formation	Wonoka Formation
					Wearing Dolomite	Wearing Dolomite	Wearing Dolomite
					Bunyerroo Formation	Bunyerroo Formation	Bunyerroo Formation
	ARUHNA SUBGROUP	hiatus	hiatus	hiatus	Wilcollo Sst.	Wilcollo Sst.	Wilcollo Sst.
					ABC Range Quartzite	ABC Range Quartzite	ABC Range Quartzite
					ABC Range Quartzite	ABC Range Quartzite	ABC Range Quartzite
WILPENA GROUP	SANDISON SUBGROUP	Simmens Quartzite	ABC Range Quartzite	ABC Range Quartzite	Urupa Siltstone	Bayley Range Siltst. Mbr.	Urupa Siltstone
		Corraberra Sandstone Member	Corraberra Sandstone Member	Corraberra Sandstone Member		Maorillah Siltstone Member	
		Lincoln Gap Sandstone Member	Maorillah Siltstone Member	Maorillah Siltstone Member		Maorillah Siltstone Member	
		Tregolana Shale Member	Maorillah Siltstone Member	Maorillah Siltstone Member		Maorillah Siltstone Member	
	Tent Hill Formation	Brachina Fm.	Brachina Fm.	Brachina Fm.	Urupa Siltstone	Brachina Fm.	Urupa Siltstone
		Maorillah Siltstone Member	Maorillah Siltstone Member	Maorillah Siltstone Member		Maorillah Siltstone Member	
WILPENA GROUP	no outcrop	Seacliff Sst.	Seacliff Siltstone	Seacliff Sst.	Nuccaleena Formation	Nuccaleena Formation	Nuccaleena Formation
		Nuccaleena Formation	Seacliff Siltstone	Nuccaleena Formation	Seacliff Sst.	Nuccaleena Formation	Nuccaleena Formation
UMBERATANA GROUP							

Fig. 5. Nomenclature and correlation of the Sandison Subgroup (after Dyson 1995).

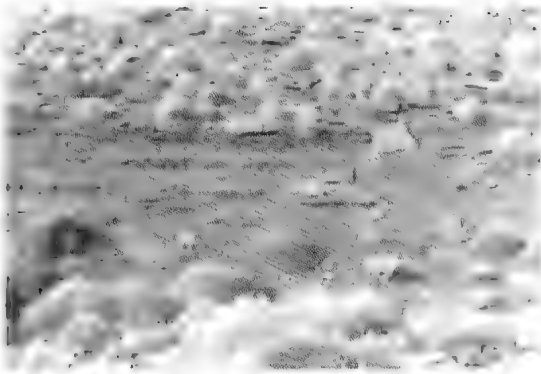


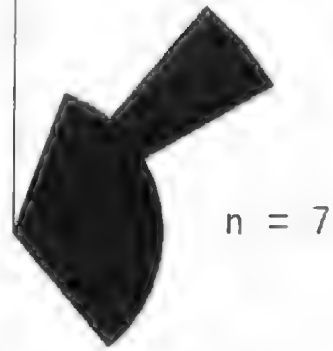
Fig. 6. Shale and very thin to thin-bedded fine-grained sandstone, Tregolana Shale Member of the Tent Hill Formation.

Individual sandstone beds are flat-based with occasional grooves and scratches. Internally, the sandstones display parallel lamination and current ripple cross-lamination analogous to the Bouma sequence for turbidites and are interpreted as having been deposited at or below storm wave base from waning, unidirectional currents of storm origin. Siltstone beds are characterised by parallel lamination. The thickness and frequency of the sandstone beds increases up-section as the Tregolana Shale Member grades into the Lincoln Gap Siltstone Member. The Tregolana Shale Member was deposited below storm wave base and is a lateral equivalent of the Moolooloo Siltstone Member of the Brachina Formation.

Lincoln Gap Siltstone Member (new name)

The name for this new member of the Tent Hill Formation is derived from "Lincoln Gap", 24 km south of South Tent Hill. It resurrects, in part, the former "Lincoln Gap Flagstones" of Miles (1955) that was previously used to include the sandy succession above the Tregolana Shale. Here, the Lincoln Gap Siltstone Member is used to describe the lower half of the Corraberra Sandstone Member that was originally defined by Thomson (1965). It is about 40 m thick and consists of interbedded greyish red shale and thin to medium-bedded, fine-grained greyish brown sandstone. Flute casts and scratch marks are common at the base of sandstone beds suggesting current transport to the east (Fig. 7). Internally, the sandstones commonly display horizontal planar lamination. They are, in places, capped by interference ripples or asymmetrical ripples with sinuous crests. Sandstones displaying planar lamination or hummocky cross-stratification (HCS) are capped by near-symmetrical ripples. Crests of the near-symmetrical ripples show a

FLUTE CASTS



WAVE RIPPLE CRESTS



Fig. 7. Palaeocurrent data for the Lincoln Gap Siltstone Member

hexagonal pattern or are straight to wavy with tuning-fork bifurcations.

Planar-laminated sandstone beds capped by current ripples are interpreted as Bouma BC sequences and suggest deposition at or below storm wave base in a current-dominated environment. The flute casts suggest the influence of unidirectional currents that were directed off-shore (Fig. 7). Ripple marks on top of these sandstone beds indicate the influence of unidirectional and oscillatory currents, resulting in combined-flow ripples (Fig. 8). The presence of

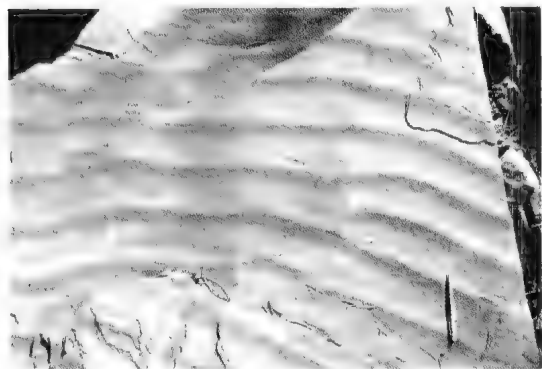


Fig. 8. Combined-flow ripples on top of fine-grained sandstone, Lincoln Gap Siltstone Member. The ripple crests show imperfect bifurcation and note the presence of wrinkle marks.

HCS and planar lamination indicates that storms were responsible for the generation of both unidirectional and oscillatory currents. Near-symmetrical ripples are interpreted as wave-formed in origin. The orientation of wave ripples suggests a north-south palaeoshoreline. These structures suggest deposition above storm wave base but below

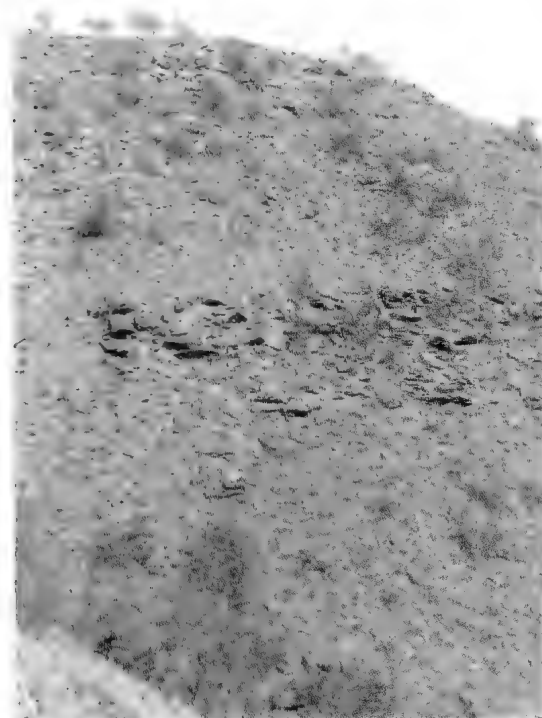


Fig. 9. Chocolate-brown sandstone of the Corraberra Sandstone Member in the centre-foreground, gradationally overlain by quartzarenites of the Simmens Quartzite.

fairweather wave base. The Lincoln Gap Siltstone Member represents deposition in an environment where oscillatory currents were dominant over unidirectional currents. It is a lateral equivalent of the Moorillah Siltstone Member of the Brachina Formation and is sharply overlain by the Corraberra Sandstone Member.

Corraberra Sandstone Member

The Corraberra Sandstone Member is about 25 m thick and consists of greyish red, iron-stained, fine to medium-grained sandstone (Fig. 9) interbedded with greyish brown shale. The sandstone beds are commonly micaceous and display heavy mineral lamination, swaley cross-stratification (Fig. 10), quasi-planar lamination (Fig. 11) and medium-scale cross-bedding. They are, in places, capped by symmetrical and asymmetrical ripples, interpreted as wave and current ripples, respectively. Glauconite, intraformational mud clasts, mud drapes, foreset bundles, climbing ripple cross-lamination and herringbone cross-lamination are also present. Several upward-sanding cycles, commonly about 5 m thick, are present in the Corraberra Sandstone Member where swaley cross-stratified sandstone beds are commonly erosive into underlying cycles that comprise tidal sand sheets. The Corraberra Sandstone Member grades upward into the Simmens Quartzite (Figs 3, 9).

The lamination and cross-stratification styles within the Corraberra Sandstone Member suggest initial deposition at or above fairweather wave base in a shoreface environment where oscillatory-dominant storm currents were operative. Cross-bedding near the top of the unit suggests the increasing influence of tidal currents. A tidally-influenced marine environment is also indicated by the presence of glauconite, bipolar cross-lamination and foreset bundles. The disconformity at the base of the Corraberra Sandstone Member marks the onset



Fig. 10. Medium-grained sandstone of the Corraberra Sandstone Member displaying SCS. Hammer for scale.

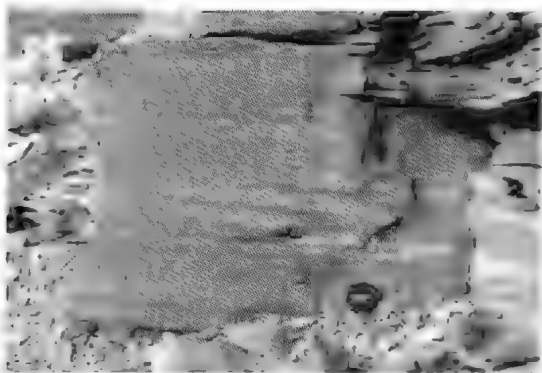


Fig. 11. Quasi-planar lamination in medium-grained sandstone, Corraberra Sandstone Member. Note presence of low-angle cross-bedding showing palaeoflow to the right. Lens cap is 52 mm in diameter.

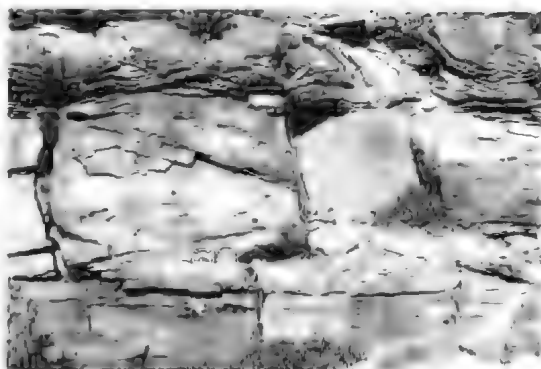


Fig. 12. Quartzarenite of the Simmens Quartzite displaying overturned cross-bedding of tidal origin and SCS. Note small-scale herringbone cross-bedding at base of bed. Brunton compass for scale.

of forced regression in the Sandison Subgroup and metre-thick, swaley cross-stratified sandstone beds are interpreted as forced regressive deposits (Dyson 1995, 1996a). Upward-shallowing cycles are interpreted as parasequences in the terminology of Van Wagoner (1985). On the Stuart Shelf, the Corraberra Sandstone Member represents partial lateral equivalents of the lower ABC Range Quartzite and upper Braehina Formation from the Adelaide Geosyncline. The iron-rich facies are similar to equivalents that crop out east of the Torrens Hinge Zone at Kulpara, Ochre Cove, Hallett Cove and Puttapa Gap (Fig. 1). It is thought that the iron was derived from erosion of the Mesoproterozoic Pandurra Formation on the Gawler Craton.

Simmens Quartzite

The Simmens Quartzite is about 100 m thick and consists of grey to greyish-white, fine to medium-grained, thin to very thick-bedded quartzarenite. These beds contain various clasts of volcanic and granitic composition, varying in size up to 20 mm. Compound cross-bedded sets comprising herringbone cross-stratification, sigmoidal cross-bedding displaying foreset bundles, planar-tabular cross-bedding, shale clasts, horizontal-planar lamination and minor swaley cross-stratification (SCS) are abundant (Figs 12, 13). Large-scale, trough cross-bedding is common (Fig. 14).

Compound cross-bedded sandstone suggests deposition of sand waves in a tide-dominated environment where asymmetry of the dominant and subordinate currents was pronounced, but bipolar currents were significant. The lack of HCS and SCS, except near the base of the Simmens Quartzite suggests shoreface deposition above fairweather wave base where tidal currents were dominant.

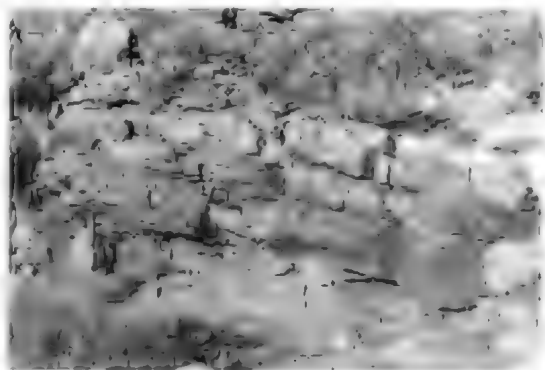


Fig. 13. Compound cross-bedding in quartzarenite of the Simmens Quartzite.

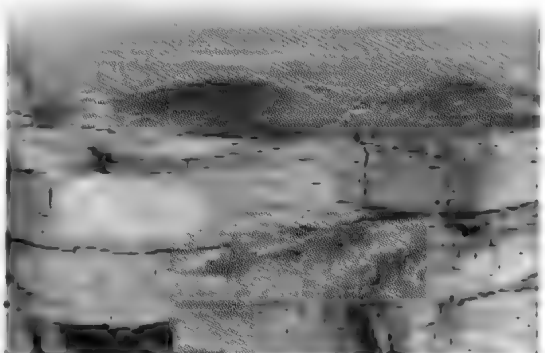


Fig. 14. Trough cross-bedding in the Simmens Quartzite. Lens cap is 52 mm in diameter.

Palaeocurrent data show a strong trend towards the east and are interpreted as reflecting progradation of ebb-flow tidal sand sheets (Fig. 15). Following Coats (1965), the Simmens Quartzite is correlated with the ABC Range Quartzite in the Adelaide Geosyncline.

Sequence boundary

The upper boundary of the Simmens Quartzite does not crop out at South Tent Hill. However, south of Bill's Lookout near the north-western side of Lake Torrens, an erosively-based sandstone at the top of the Simmens Quartzite crops out poorly where it is conformably overlain by moderate brown to greyish green shale of the Yarloo Shale. The metre-thick, medium-grained off-white sandstone contains basal clasts of shale, lithic sandstone and occasional volcanics. Sedimentary structures include trough cross-bedding, SCS and symmetrical ripples.

The erosively-based sandstone at the top of the Simmens Quartzite is interpreted as having been deposited in an estuarine environment. The style of cross-bedding in the lower part of the unit suggests deposition on a fluvially-dominated shoreface. A storm influence is indicated by the presence of SCS

and the symmetrical ripples are interpreted as having been formed by wave action. This unit is a possible equivalent of the Wilcolo Sandstone that overlies the ABC Range Quartzite in the Adelaide Geosyncline where it marks the development of broad (c. 10–20 km) incised valley fills that in places attain a thickness of some 25–50 m in outcrop. They consist of a basal, trough cross-bedded facies of fluvial origin, overlain by SCS shoreface sands. The SCS shoreface sands pass rapidly upward into basinal shale of the Bunyeroo Formation. The Wilcolo Sandstone and Bunyeroo Formation together constitute the Aruhna Subgroup (Dyson 1996b). Its upper boundary is represented by the maximum flooding surface at the base of the Wearing Dolomite which is coincident with the development of kilometre-deep canyons previously assigned to the overlying Wonoka Formation (Dyson 1995¹, 1996b).

Stratigraphic equivalents of the Tent Hill Formation and Simmens Quartzite

The redefined Tent Hill Formation and Simmens Quartzite may be considered partial lateral equivalents of the Brachina Formation, ABC Range Quartzite and Ulupa Siltstone in the Adelaide Geosyncline (Fig. 5). The Brachina Formation was defined by Dalgarno & Johnson (1964) as the thick succession of siltstone conformably overlying the Nuccaleena Formation and passing upwards into the ABC Range Quartzite (Mawson 1939). Together with the Seaciff Sandstone and Nuccaleena Formation, the Brachina Formation and ABC Range Quartzite were incorporated into the Sandison Subgroup (Dyson 1992). The Brachina Formation and ABC Range Quartzite crop out at several localities within the Mount Lofty and Flinders ranges, of which the latter occurrences appear to display lateral continuity. A study by Dyson (1992, 1995¹) focused on well-exposed sections at Hallett Cove, Ochre Cove, Mount Terrible, Kulpara, Hidden Gorge, Wyacea Bluff, Partacoona and Bunyeroo Gorge (Fig. 1). The Ulupa Siltstone is best developed to the east and northeast parts of the Adelaide Geosyncline on the BURRA, COPLEY, OLARY, ORROROO and MARREE 1:250 000 geological sheets. The Brachina Formation and overlying ABC Range Quartzite constitute an overall upward-sanding succession. They represent regressive sedimentation of the Sandison Subgroup and are therefore defined as all the strata overlying the maximum flooding surface/downlap surface, represented by the Nuccaleena Formation, to the sequence boundary at the base of the Aruhna Subgroup.

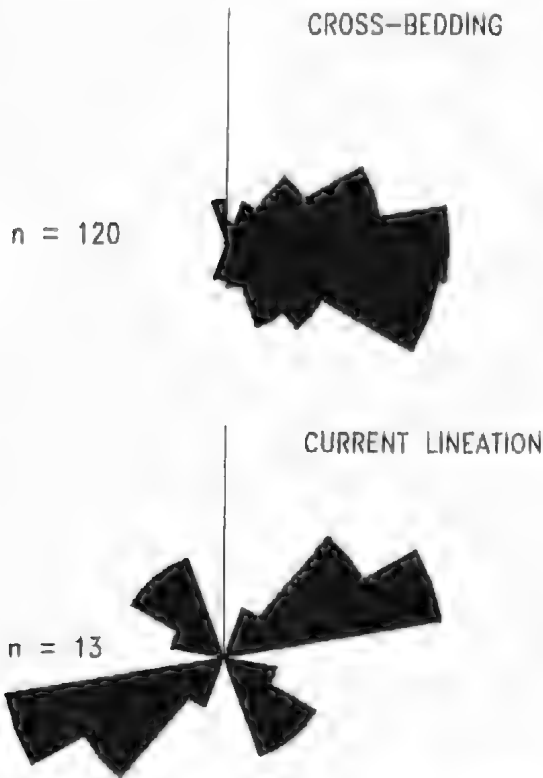


Fig. 15. Palaeocurrent data for the Simmens Quartzite.

Brachina Formation

The Brachina Formation comprises four members, each of which can be defined by its lithofacies (Fig. 5). Two of these, namely the Bayley Range Siltstone Member and the Corraberra Sandstone Member, are considered lateral equivalents (Dyson 1995¹). The Bayley Range Siltstone Member does not crop out at Hallett Cove or Kulpura (Fig. 1). The Corraberra Sandstone Member of the Tent Hill Formation that crops out on the Stuart Shelf has an equivalent that is included in the Brachina Formation at Hallett Cove (Dyson 1995¹). The lithofacies of the Brachina Formation at Hallett Cove display a suite of sedimentary structures suggestive of deposition under the influence of great storms. These structures, including accompanying palaeocurrent data, are illustrated and described more fully by Dyson (1995¹, 1995).

ABC Range Quartzite

The ABC Range Quartzite is composed of pale pinkish grey to greyish white, thick-bedded to massive, fine to medium-grained, slightly feldspathic quartzite and minor interbedded shale and fine-grained sandstone. It is characterised by the abundance of planar-tabular, herringbone and large-scale trough cross-bedding, asymmetrical ripples with sinuous crests, flaser and lenticular bedding, mudcracks, mud drapes and mud intraclasts. Straight-crested symmetrical ripples also cap some sandstone beds. Compound cross-bedded sets consist of small-scale cross-bedding separated by inclined, master set boundaries. As the inclination of the master bedding planes decreases, the bipolarity of the cross-bedding becomes more prevalent. Megaripple cross-bedded sets, commonly unidirectional, display a thin-thick alternation of sandy foreset bundles, bounded by reactivation surfaces, mud couplets and/or mud drapes. Sandstone channels are characterised by gently inclined lateral accretion surfaces and low-angle truncation surfaces. SCS and horizontal-planar lamination are occasionally observed near the base of some minor quartzite units. HCS is restricted to intervals of interbedded shale and thin to medium-bedded fine sandstone and quartzite. Thus, the suite of sedimentary structures in the ABC Range Quartzite described here suggests that it was deposited in a shallow marine environment where tidal currents were dominant over storm and wave action.

Ulupe Siltstone

The Ulupe Siltstone is a regionally significant unit that can be mapped over a large area of the Adelaide Geosyncline. The type section of the Ulupe Siltstone was defined by Mirams (1964) near Mount Bryan on BURRA where it was described as a succession of

green, grey and locally purple shales. Plummer (1978) recognised the three members of the Brachina Formation in the Ulupe Siltstone at Godda Witra (Figs 1, 5) and recommended the term "Ulupe Siltstone" be relinquished. However, Forbes & Preiss (1987) proposed retention of the stratigraphic name because they argued that regional mappability of the constituent members had not been established. Lithofacies of the Ulupe Siltstone are distal equivalents of the constituent members of the Brachina Formation and are therefore time-transgressive. The Ulupe Siltstone represents regressive shallow marine sedimentation on the middle to outer shelf. Palaeocurrent data show a wide range of current directions (Dyson 1995¹), suggesting an environment where unidirectional and oscillatory currents were interactive.

Depositional model for the Tent Hill Formation and Simmens Quartzite

The Simmens Quartzite and constituent members of the Tent Hill Formation may be defined by their lithofacies. The Tent Hill Formation is an upward-sanding succession of interbedded shale and fine-grained sandstone. Sandstone beds display several sedimentary structures associated with storm deposition such as BC Bouma sequences, HCS, micro-HCS and quasi-planar lamination. The Tregolana Shale Member was deposited below storm wave base. With progressive shallowing above storm wave base, interbedded shale and sandstone of the Lincoln Gap Siltstone Member were deposited. At the top of this succession, the Corraberra Sandstone Member consists of several sharp-based shoreface sandstones about 1-2 m thick that display SCS. These SCS sandstones are referred to as attached shoreface deposits. Some SCS sandstones are completely enclosed within shale and are referred to as detached shoreface deposits. The base of each SCS sandstone is a high-frequency sequence boundary. The erosive shoreface deposits are interpreted as forced regressive deposits. The Corraberra Sandstone Member was deposited above fairweather wave base in an environment that was storm-dominated but where tidal activity was also significant. It is gradationally overlain by parasequences of tide-dominated quartzarenites and lithic sandstones of the Simmens Quartzite. The Simmens Quartzite represents continued shallowing of the sea in which the Tent Hill and Brachina Formations were deposited. Combined with a high sediment supply, progradation of the lower shoreface resulted in a wide, shallow shelf which was conducive to tidal amplification. No submarine fan deposits have been recognised at this stratigraphic level elsewhere in the basin.

The Tent Hill Formation and Simmens Quartzite represent progradation of a tide-dominated shoreline into a storm-dominated, shallow shelf environment. This regressive succession is composed of a number of upward-sanding cycles that are contained within a hierarchy of transgressive-regressive cycles. These cycles are initially aggradational in character and become increasingly progradational upsection. A very thick offlap wedge developed from this progradation and gravitational instability resulted in extensional faulting and enhanced subsidence. Palaeocurrent data suggest a north-south, tidally-influenced shoreline. Sediment was derived from the Gawler Craton to the west and transported eastwards. The depositional environment shallowed to above fairweather wave base across a relatively narrow shelf and sediment prograded across the Torrens Hinge Zone into the Adelaide Geosyncline. Here, thickness of the Sandison Subgroup was affected by syn-depositional tectonics. Coats (1965) suggested that the overlying Wonoka Formation and Pound Subgroup were not deposited on the Stuart Shelf, but were restricted to the Adelaide Geosyncline because of syn-depositional faulting across the Torrens Hinge Zone. The arcuate trend represented by the Torrens Hinge Zone marked the possible edge of the former shelf during deposition of the lower Wonoka Formation. However, identification of the Wonoka Formation in drillcore from the eastern Stuart Shelf (e.g., Bopeechee 2) suggests that a major transgression occurred across the Torrens Hinge Zone at this time. Deposition of thick Bunyeruo sediments in the Adelaide Geosyncline was contemporaneous with active subsidence. Regional instability contributed to the incision of Wonoka canyons on the western edge of the Geosyncline.

Discussion

Forced regressive deposits

In the classic Exxon sequence stratigraphic model, the Type 1 depositional sequence consists of lowstand, transgressive and highstand systems tracts which are schematically tied to specific increments of the eustatic curve. However, an increasing volume of literature suggests that deposition during a relative fall in sea level may be placed into a fourth systems tract between the highstand systems tract (HST) and the sequence boundary. This systems tract has been previously referred to as the falling stage or forced regressive systems tract (e.g., Hunt & Tucker 1992). Study of progradational tidal sand sheets and sharp-based shoreface deposits of the Tent Hill Formation and Simmens Quartzite at South Tent Hill, and similar deposits of the Brachina Formation and ABC Range Quartzite at Hallett Cove, Koolpara, Bunyeruo Gorge and Trebilcock Gap (Fig. 1) suggests that they

may be assigned to the falling stage systems tract (Dyson 1996a). These units represent regressive sedimentation of the Sandison Subgroup on the Stuart Shelf and in the Adelaide Geosyncline. The lower and upper boundaries of the the falling stage systems tract (FSST) are fixed on the relative sea level curve. However, the increments of the other systems tracts are not fixed and will vary due to subsidence rate and sediment supply. Shoreface sandstone displaying SCS at the base of the Corraberra Sandstone Member corresponds to the base of the FSST. Its upper boundary is the sequence boundary which is defined here as the lowest point of relative sea level. The correlative conformity may be analogous to the downlap surface or disconformity at the top of submarine fans in earlier Exxon models. It passes updip into the subaerial unconformity associated with the sequence boundary.

Shelf dynamics and palaeocurrents

Shoreface storm deposits of the Corraberra Sandstone Member were possibly deposited in a mesotidal environment with a tidal range of some 2–4 m. Such environments are storm or wave-dominated (Dalrymple 1992). The Corraberra Sandstone Member is directly succeeded by tidal sand sheet deposits of the ABC Range Quartzite in the southern part of the Adelaide Geosyncline. This suggests that tidal overprinting of storm and wave effects extended well out across the upper shoreface. The relative influence of storms decreased as the tidal current speeds increased, so that distal parts of the sand sheet contained storm-generated structures. The storm-dominated shoreface system was replaced by prograding tide-dominated deltas and open coast tidal flats. Mud was deposited beyond the depth and range of tidal reworking. Tidal channels within the Simmens Quartzite were possibly incised to shallow subtidal depths on the shoreface, based on the rarity of SCS. The depth of incision suggests a high mesotidal to possible macrotidal range along the palaeoshoreline. During deposition of the FSST, tidal range may have been limited due to the relative fall in sea level.

Wave ripple orientations suggest a regional north-south shoreline. Clastic material was sourced from the west. Asymmetry of the tidal regime is supported by the dominant unimodal trend for ripple cross-bedding. The wide spread of these data suggests that longshore currents were operative. Shoaling fairweather and storm waves initiated longshore currents that transported sand on the shoreface, roughly parallel to the shoreline. Palaeocurrent data from storm-influenced lithofacies in the Brachina Formation at Hallett Cove are described by Dyson (1995, 1995).

Lithofacies relationships and correlations

The Corraberra Sandstone Member of the Tent Hill Formation at South Tent Hill and on the Stuart Shelf comprises the lower part of the sandy succession overlying the Tregolana Shale Member (Crawford 1964). Lithofacies resembling those of the Corraberra Sandstone Member also crop out at Ochre Cove (Dyson 1995¹), Hallett Cove and Kulpara (Dyson 1992) and at Puttapa Gap near Beltana (Coats 1965). Granular, medium to coarse-grained sandstone and dark red to reddish brown shale at Ochre Cove (Fig. 1), previously identified as Bunyerou Formation (Dyson 1992), was reinterpreted as lithofacies of the Corraberra Sandstone Member of the Brachina Formation (Dyson 1995¹). At Kulpara, facies of the Corraberra Sandstone Member are interbedded with the lower ABC Range Quartzite. The Bayley Range Siltstone Member crops out north of Pichi Richi Pass at Middle Gorge, Partacoona, Warrakimbo Gorge, Black Gap, Bunyerou Gorge, Brachina Gorge and Finke Springs (Fig. 1). South of Partacoona and adjacent to the Torrens Hinge Zone, the storm-dominated facies of the Corraberra Sandstone Member are predominant. This suggests that the Corraberra Sandstone and Bayley Range Siltstone members, both deposited above fairweather wave base, are lateral equivalents. Furthermore, they are partial lateral equivalents of the lower ABC Range Quartzite.

The terms "Simmens Quartzite" and "ABC Range Quartzite" are used herein to describe silica-cemented quartzite or orthoquartzite in which the dominant mineralogy is over 90% quartz. Pettijohn *et al.* (1972) prefer the use of the term "quartzarenite" over "orthoquartzite" for those sediments in which the detrital fraction is 95% or more quartz. The ABC Range Quartzite has been mapped at the first appearance of thick, laterally extensive white quartzite (e.g., Webb & von der Borch 1962; Dalgarno & Johnson 1966). Apparent intertonguing of the Tent Hill Formation and Simmens Quartzite on the Stuart Shelf, and between the Brachina Formation and ABC Range Quartzite in the Adelaide Geosyncline can be generated by the stacking of these lithofacies on a parasequence scale. Similarly, intertonguing between the constituent members of the Brachina Formation and Tent Hill Formation may be explained in this manner.

Acknowledgments

The study of the Tent Hill Formation and Simmens Quartzite comprised part of a PhD dissertation by the author at Flinders University. Wolfgang Preiss and an anonymous reviewer read the manuscript critically and contributed many helpful suggestions. Gail Jackson and Ghazi Kraishnan drafted the figures.

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TRANSACTIONS OF THE

ROYAL SOCIETY

OF SOUTH AUSTRALIA

INCORPORATED

VOL. 120, PART 4

**BIOLOGY OF THE EUCALYPT GALL-FORMING FLY,
FERGUSONINA FLAVICORNIS MALLOCH (DIPTERA:
FERGUSONINIDAE) AND ITS ASSOCIATED
HYMENOPTERANS IN SOUTH AUSTRALIA, WITH A
DESCRIPTION OF A NEW SPECIES OF BRACON
(HYMENOPTERA: BRACONIDAE)**

By G. S. TAYLOR, A. D. AUSTIN & K. A. DAVIES¹

Summary

Taylor, G. S., Austin, A. D. & Davies, K. A. (1996) Biology of the eucalypt gall-forming fly *Fergusonina flavicornis* Malloch (Diptera: Fergusoninidae) and its associated hymenopterans in South Australia, with a description of a new species of *Bracon* (Hymenoptera: Braconidae). Trans. R. Soc. S. Aust. 120(4), 131-146, 29 November, 1996.

Galls initiated by the association of *Fergusonina flavicornis* Malloch (Insecta: Diptera: Fergusoninidae) and *Fergusobia* sp. (Nematoda: Sphaerulariidae) on *Eucalyptus camaldulensis* Dehnh. at Goolwa, South Australia were monitored during a single, late summer generation for emergence of flies and associated Hymenoptera. The morphology of the galls is described for the first time. A total of 12 hymenopteran species was reared from galls, twice the number previously recorded from *Fergusonina*/*Fergusobia* galls. There was a strong positive correlation between emergence of flies, combined totals of flies and wasps and gall size. *Bracon fergusoninus* sp. nov., a probable primary parasitoid of *F. flavicornis* larvae, is described. Notes on the biology and taxonomy of each hymenopteran species are presented along with an illustrated key to their identification.

Key Words: *Eucalyptus*, gall-forming, *Fergusonina*, Diptera, Fergusoninidae, parasitic Hymenoptera, Braconidae, *Bracon*, *Fergusobia*, Nematoda, Sphaerulariidae.

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Introduction

The biology of gall-associated Hymenoptera is fundamentally complex and it is often extremely difficult to determine the true relationships of species (Bouček 1988; Gough & McMahon 1988; Naumann 1991; Schönrogge *et al.* 1996). For instance, galls may contain a range of biologically different Hymenoptera, viz., primary parasitoids, facultative and obligate hyperparasitoids and inquilines. The biology of the latter group is particularly difficult to unravel. Inquilines are species that live inside galls of other cecidogenic insects and are phytophagous for all or some of their larval development. They often kill the primary gall-forming species at an early stage of gall development and then increase the size of the gall, thereby making it difficult to determine whether or not the species concerned is indeed an inquiline or the primary gall-former. Other inquilines apparently invade galls and feed on their tissues without disrupting the primary cecidogenic species.

One of the most complex gall associations known is that between *Fergusonina* spp. (Insecta: Diptera: Fergusoninidae) and *Fergusobia* spp. (Nematoda: Tylenchida: Sphaerulariidae) in galls on Myrtaceae (Fisher & Nickle 1968; Harris 1982; Davies & Lloyd 1996). However, the only detailed study of the

biology and phenology of *Fergusonina* Malloch flies is that of Currie (1937), who commented on the possible role of hymenopterans and other gall inquilines in the seasonal fluctuations of fly populations. This study showed that numerous wasps were associated with *Fergusonina*/*Fergusobia* flower bud galls. Although Currie (1937) examined the biology of this system, the taxonomic knowledge at the time was limited and the biology of the species involved was not well understood.

This paper reports on a study of the leaf galls of *Fergusonina flavicornis* Malloch associated with an undescribed species of *Fergusobia* Currie and the associated guild of hymenopterans from galls on *Eucalyptus camaldulensis* Dehn. at Goolwa, South Australia. Information is presented on gall morphology, the phenology of the fly and wasps, the probable biology of the hymenopteran species involved, their taxonomy, and the relationship between numbers of flies and wasps and gall size. A new species of *Braccon* F., thought to be a primary parasitoid of *Fergusonina*, is described and an illustrated key to the 12 gall-associated hymenopterans is presented. This information is compared with Currie's (1937) study and is discussed in relation to the inherent difficulties in determining the biology of gall associated wasps.

Materials and Methods

Seven mature galls on an ornamental, 4 m high *E. camaldulensis* sapling at Goolwa, (35°31' S,

¹ Department of Crop Protection, Waite Campus The University of Adelaide PMB 1 Glen Osmond S. Aust 5064

138°46' E) South Australia were caged with muslin in early March, 1995, preceding emergence of adult *F. flavicornis* and other gall occupants, and periodically monitored until after senescence of the gall and when flies and wasps ceased to emerge. Any insects that had emerged at each sampling time were collected, identified and counted. Galls were dried and weighed to compare gall mass with total insect emergences. For observations on gall development and morphology, young fresh galls were sliced open in water by a series of transverse cuts. Abbreviations used are: ANIC (Australian National Insect Collection, CSIRO, Canberra) and WARI (Duncan Swan Insect Collection, Waite Campus, The University of Adelaide). Voucher material of *F. flavicornis* has been lodged at ANIC and WARI and material of all hymenopteran species is deposited in WARI.

Results and Observations

Distribution and host plant association

Fergusonina flavicornis was the only dipteran reared from an ornamental specimen of *E. camaldulensis* at Goolwa. Similar galls have been collected by us from several other South Australian localities from naturally-occurring *E. camaldulensis* near Verdun and near Milang, and from this same host in the Adelaide suburbs of Hyde Park, Rose Park, Tasmore and Urribrae. *Fergusonina flavicornis* was described from a single female specimen from Sydney, NSW (Malloch 1925). Larvae, males and galls have remained undescribed to date. This is the first host plant record for the species and first description of the gall (see below). We have also collected all life history stages of *F. flavicornis* and the associated, undescribed species of *Fergusonia* and plan to discuss these in a separate publication.

Gall morphology and formation

The galls of *F. flavicornis* are formed from terminal leaf buds, mature galls (Fig. 1) being bulbous structures, mostly ovoid in longitudinal cross section, 18–50 mm in length by 12–20 mm in diameter. Mean dry weight of mature galls was 2.22 ± 1.45 g (range 0.89–5.16 g, $n = 7$). Galls appear to consist of a single leaf bud comprising a number of leaves, with the ventral surface of the outermost forming the external face of the gall. The growth of these outer leaves sometimes continues unaffected beyond the gall proper, either running along the side of the gall or emerging as normal leaf tissue beyond its apex. The stem supporting the gall usually develops a bend just before its insertion in the base of the gall. Transverse sections showed that the galled tissue is soft, consisting of parenchymatous tissue, and that *F. flavicornis* larvae develop in

discrete cavities. These are oval in longitudinal outline and distributed throughout the gall. The cavities are lined with plant cells which are paler in colour than the parenchyma cells between them. *Fergusonia* nematodes are found in the cavities with the fly larvae.

For the generation of *F. flavicornis* which began in late March, small, recently initiated galls were observed. Four of these were collected and dissected and the development of others was monitored during the study. Full gall size was reached on the tree in two to four weeks from gall initiation. The following observations were made on the dissected galls. The smallest gall, 8 mm in length contained 20 spindle-shaped *F. flavicornis* eggs (Fig. 2) within which developing larvae could be seen. It contained many parthenogenetic and juvenile nematodes and some nematode eggs. At this stage of development no cavities were present. Another, 10 mm long, contained several eggs, a few first instar larvae of *Fergusonia* and many parthenogenetic nematodes and eggs. Some fly larvae were found within cavities, the small cavities being ringed with many white cells. A 12 mm long gall contained first and second instar larvae of *Fergusonia*, all within cavities, and many parthenogenetic nematodes and eggs. The largest gall, about 30 mm in length, contained first and second instar fly larvae within



Fig. 1. Terminal leaf bud gall of *Fergusonina flavicornis*/*Fergusonia* on *Eucalyptus camaldulensis* at Goolwa, South Australia. Scale bar = 25 mm.



Fig. 2. Egg of *Fergusonina flavicornis* from a terminal leaf bud gall from *Eucalyptus camaldulensis* at Goolwa, South Australia. Scale bar = 0.25 mm.

well-defined cavities, none of which was ringed with white cells. It contained many parthenogenetic female, juvenile and male nematodes and eggs. The three larger galls each contained brown 'streaks', running from the centre to the outer edges, apparently formed by the darkening of intact plant cell walls. These observations on the process of gall induction indicate that *F. flavicornis* and nematodes are always present together and that both fly larvae and nematodes continue to develop, thus increasing the size of the cavities. We have not been able to determine whether gall initiation requires both species to be present or if only one is required. Given that nematodes are present in the early gall matrix prior to hatching of fly eggs, it is possible that initially, gall tissue is produced in response to nematode secretions (see Discussion).

Egg and dorsal shield of *Fergusonina flavicornis*

The egg of *F. flavicornis* is spindle-shaped and tapers to a short, blunt 'pedicel' at the micropylar (anterior) end and to a somewhat longer, tapered process at the other end (Fig. 2). The egg is $0.65 \pm \text{SE } 0.06$ mm long by $0.26 \pm \text{SE } 0.03$ mm wide ($n = 4$). It is larger than the egg of *F. nicholsoni* Tonnoir which was described and illustrated by Currie (1937).

Second and third instar larvae of most described species of *Fergusonina* have a more or less elaborate dorsal shield (Currie 1937). In *F. flavicornis* it consists of a sclerotised modification to the second and third thoracic segments and first abdominal segment comprising a plate with sometimes three,

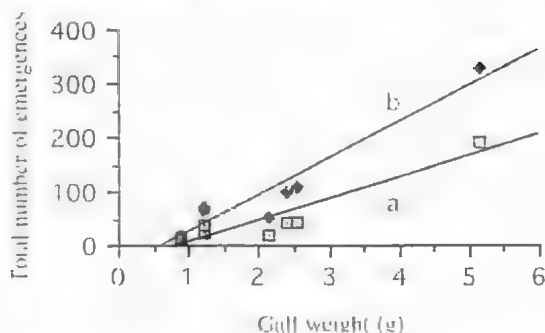


Fig. 3. Relationship between total number of emergences per gall for (a) *Fergusonina flavicornis* alone, and (b) *F. flavicornis* plus associated Hymenoptera versus gull weight (in grams), reared between 5 March and 30 April 1995 from *Eucalyptus camaldulensis* at Goolwa, South Australia.

mostly four and rarely five anteriorly projecting prongs arising from the third thoracic segment. The structure of the shield is similar to that depicted for *F. lockharti* Tonnoir by Currie (1937). Its function is implicated in feeding and the enlargement of gall cavities (see Discussion). Indeed many pellets of plant material were found in the gall cavities often adhering to the dorsal shield. Faecal material within the gall cavities was not observed.

Emergence and Phenology of *Fergusonina* and associated Hymenoptera

Galls collected in late February 1995 contained only larval stages of *F. flavicornis* but pupae were present soon after. Galls were caged in the field on 5 March (day 0) and the first adult *F. flavicornis* had emerged by day 3. Adult flies continued to emerge for about the next 40 days, peaking around day 18 (23 March) (Fig. 4a). The 370 adult *F. flavicornis* that emerged from the caged galls had a sex ratio slightly biased in favour of males (1: 1.2). Further, the number of flies that emerged had a positive relationship with gall size (measured as dry gall weight) (Fig. 3, line b). However, the regression against gall size was steeper for flies plus associated Hymenoptera (Fig. 3, comparing lines a and b), and the correlation slightly better ($r^2 = 0.91$ versus 0.87), compared with flies alone. The reason for this is not clear but, presumably, gall size is a reasonable estimate of available food and so for a given gall there must be a limit to the number of flies it can support. However, all galls surveyed (Table 1) contained some Hymenoptera, and these individuals, whether they are phytophagous, parasitic on *F. flavicornis*, or both (inquilines), will have displaced or killed flies that otherwise would have completed development and emerged. Hence, the steeper slope of the regression line for flies plus Hymenoptera represents what is a closer estimate for the carrying

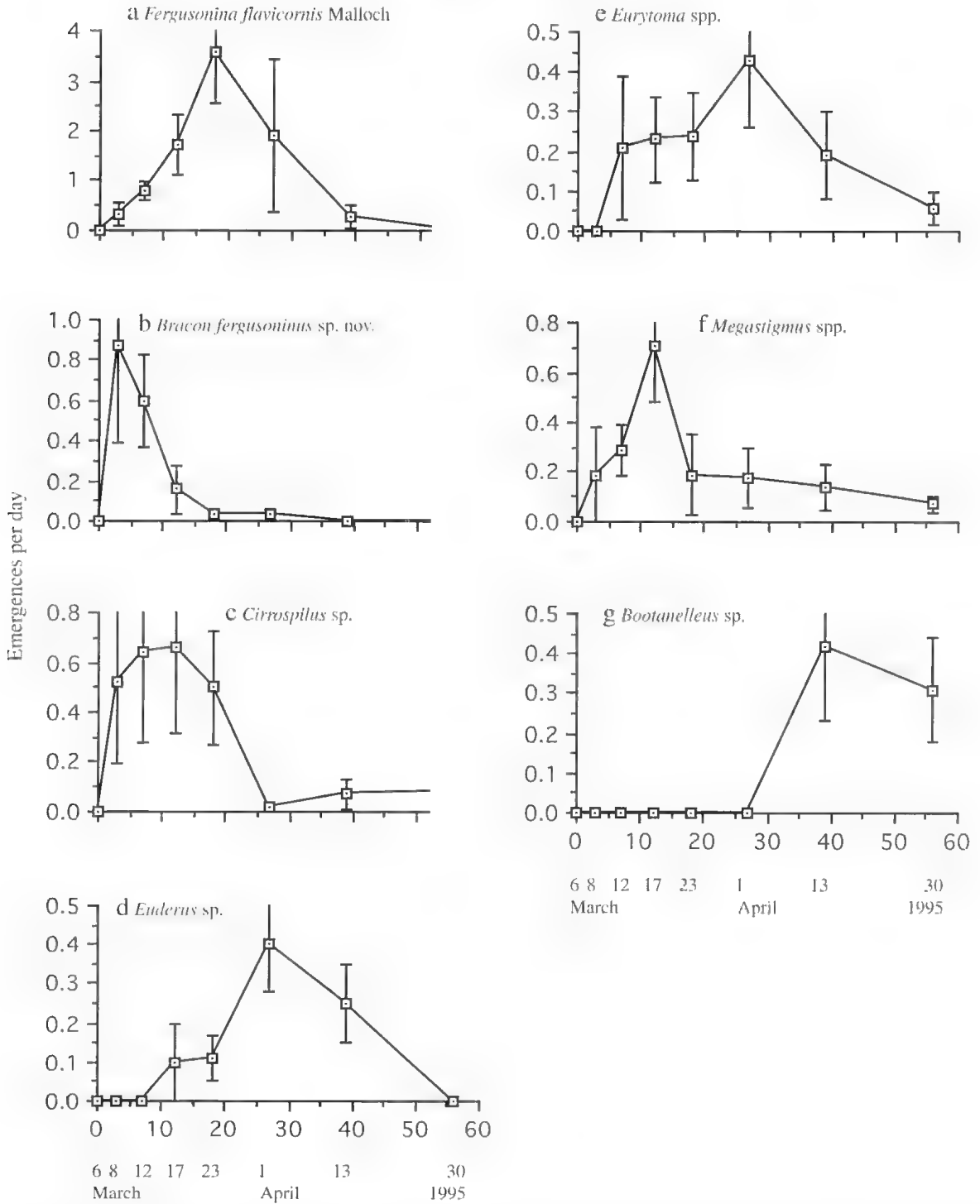


Fig. 4. Number of emergences per day for *Fergusonina flavicornis* (4a) and the six most abundant Hymenoptera (4b-4g) reared from galls between 5 March (day 0) and 30 April 1995 (day 56) on *Eucalyptus camaldulensis* at Goolwa, South Australia. The standard errors around the means are different for each species because the number of galls in which they occurred was also different (see Table 1).

TABLE 1. Total emergences from 5 March - 30 April, 1995 of *Fergusonina flavicornis* and associated hymenopterans spp. from *Fergusonina/Fergusobia* galls on *Eucalyptus camaldulensis* at Goolwa, S. Aust.

Species	Gall number							Total
	1	2	3	4	5	6	7	
<i>Fergusonina flavicornis</i> Malloch	19	24	12	44	44	189	38	370
<i>Bracon fergusoninus</i> sp. nov.	2	17	0	0	1	10	1	31
<i>Poecilotheryptus</i> spp.	0	1	0	1	2	2	0	6
<i>Cirrospilus</i> sp.	6	7	1	4	21	37	13	89
<i>Eulderus</i> sp.	3	1	0	9	8	15	8	44
<i>Pediobius</i> sp.	0	0	0	1	0	0	0	1
<i>Eurytoma</i> spp.	14	11	3	11	4	25	3	71
<i>Cnecorhiza nigricincta</i> Ashmead	0	5	1	2	2	5	0	15
<i>Ditropinotella</i> sp.	0	0	0	0	4	3	2	9
<i>Megastigmus</i> spp.	6	5	2	19	12	30	1	75
<i>Boottanellus</i> sp.	2	0	0	17	2	12	0	33
Total parasitoids	33	47	7	64	56	139	28	371

capacity of a gall in terms of food resources, compared with that for flies alone.

The composition of the hymenopteran species that emerged from caged galls varied in all cases, except between galls 5 and 6 which yielded the same species (Table 1). Galls contained an average of seven species (range = 4-9), with no gall containing all species (note that in Table 1 species for each of *Poecilotheryptus*, *Eurytoma* and *Megastigmus* have been combined). The biology of the individual hymenopteran species in this guild is discussed below. Of these, several were reared in sufficient numbers (> 30 individuals) to examine their pattern of emergence (Figs. 4b-g). *Bracon fergusoninus* sp. nov., *Cirrospilus* sp. and *Megastigmus* spp. all had a peak in their emergence prior to that of *F. flavicornis*. For *B. fergusoninus*, this peak occurred at the beginning of the study (day 3) and virtually all individuals had emerged prior to the peak of *F. flavicornis* on about day 18, while *Cirrospilus* sp. and *Megastigmus* spp. continued to emerge from galls until day 56, albeit in low numbers for most of this time. *Eulderus* sp. and *Eurytoma* spp. had a broad range of emergence times, beginning prior to the maximum in *F. flavicornis* (day 18), peaking at about day 27 and continuing to, or almost to, day 56 when the study was terminated. In contrast, *Boottanellus* sp. did not start emerging from galls until 21 days after the peak in *F. flavicornis*. Emergence of this species reached a maximum about day 39 and some individuals were still emerging from galls up to day 56. Of the other hymenopteran species that were reared in low numbers (<30 individuals), the emergence of *C. nigricincta* (days 1-27) straddled the peak for *F. flavicornis*. *Poecilotheryptus* spp. (6 individuals from days 23-39) and *Ditropinotella* sp. (9 individuals from days 28-56) emerged well after *F. flavicornis*, while the single specimen of *Pediobius*

sp. emerged between days 13 and 18 (18-23 March).

Taxonomy and biology of Hymenoptera associated with Fergusonina

During the study 12 species of Hymenoptera were reared from *Fergusonina/Fergusobia* galls on *E. camaldulensis*. This section describes some aspects of the biology of the species concerned and speculates on other aspects of their association, based on information available for other related species. Notes are provided on their taxonomy, including the description of a new species, and an illustrated key is provided to identify the 12 species.

Family Braconidae

Bracon fergusoninus sp. nov.

(FIGS 5-8)

Holotype: ♀, South Australia, Goolwa, 6-8.iii.1995, G. Taylor & K. Davies, reared from *Fergusonina* galls on *Eucalyptus* sp. (ANIC).

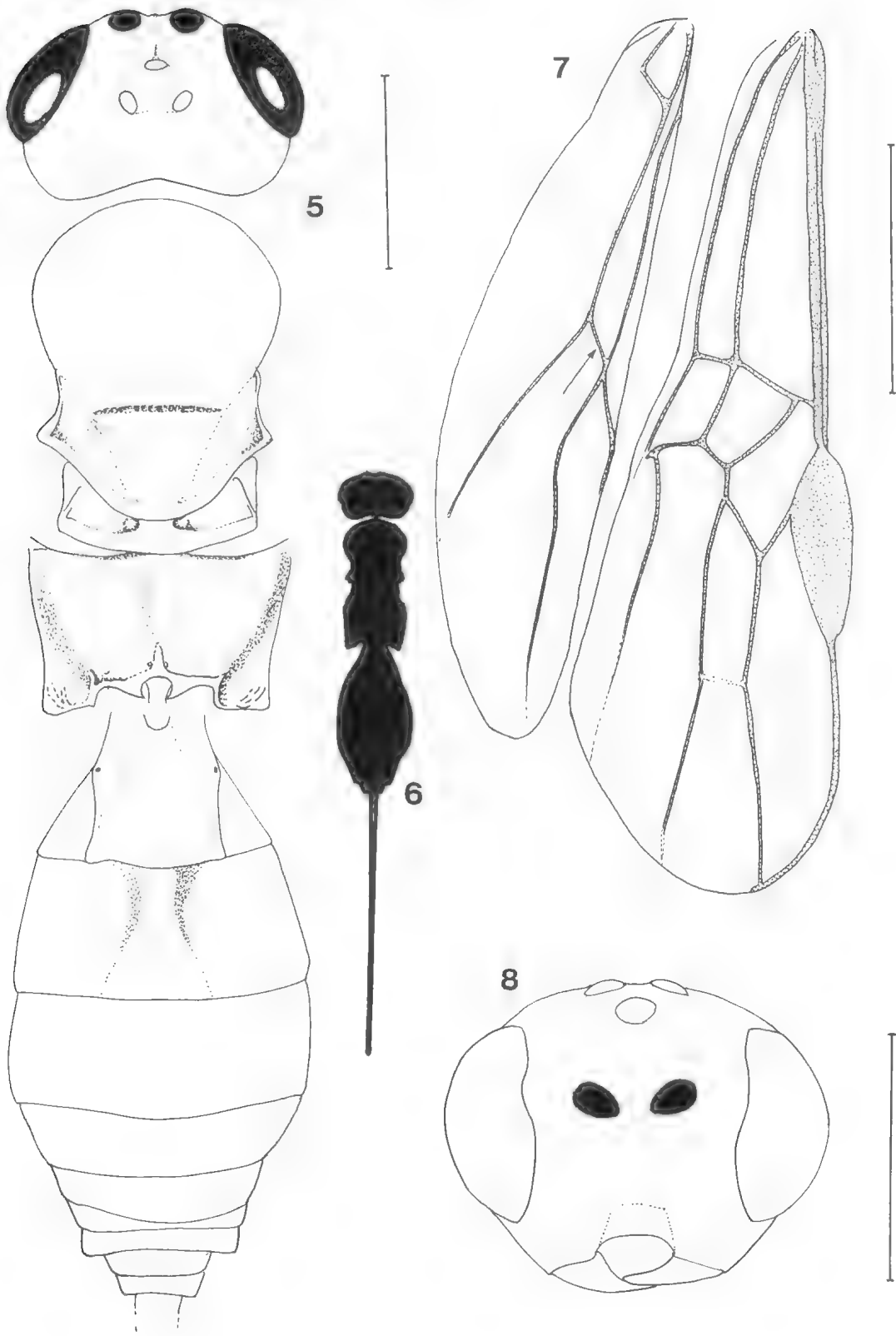
Paratypes: 8 ♀♀, 18 ♂♂, same data as holotype except some with dates as follows 9-12.iii.95, 13-17.iii.95, 24.iii.-1.iv.95 (ANIC, WARI).

Female

Size: Length 2.4-2.6 mm (excluding ovipositor).

Colour: Head, scutum, pronotum, legs and anterior two-thirds of metasoma yellow-brown to orange-brown; antennae, eyes, posterior parts of mesosoma and metasoma, distal half of hind legs, proximal, mid and hind coxa and ovipositor sheaths black; sometimes area around ocelli and posterior margin of scutum darker; wings evenly infusate.

Head: In anterior view face half width of head; eyes moderately bulbous, hairless; face, gena and mandibles evenly covered with long hairs; in dorsal view vertex, dorsal temples and lateral frons with



long hairs; in lateral view lower temple glabrous; antennae slightly longer than body; flagellomeres all longer than wide.

Mesosoma: Scutum and scutellum smooth, shiny, with a few long sparse hairs on posterior parts of each tergite; scutum with sparse hairs along lateral margin and along notauli; notauli indicated by faint depressions more prominent in posterior half; scutellar suture slightly depressed and curving posteriorly, comprising 12-14 foveate punctures; dorsal and lateral scutellum delimited by row of longish hairs; propodeum with medial longitudinal carina in posterior one-third, faintly depressed in anterior midline, with sparse long hairs in lateral part; in lateral view pronotum and mesopleuron smooth and mostly hairless; epinemial area covered with long hairs; metapleuron covered with long hairs, smooth in dorsal half, faintly rugose in postero-ventral part; legs evenly and densely setose except for outer surfaces of coxae; fore wing with 1M and 1-Rs+M faintly bowed, 2-Rs straight; 3-CU1 evenly curved; 2nd submarginal cell elongate, sides (3-Rs and 2-M) almost parallel, 1st discal cell moderately elongate (1-Rs+M 2.8 x length of m-cu). **Metasoma:** Mostly smooth throughout; sclerotised part of T1 slightly longer than wide, lateral margins with long sparse hairs, postero-medial lobe of T1 broad, faintly longitudinally striate along posterior margin, delimited by shallow lateral furrows which are pereurent to base of T1; T2 with broad medial longitudinal carina in anterior half with a few striae either side, postero-medial area very faintly raised and triangular; T2 and T3 subequal in length and comprising about one-third length of metasoma, with sparse long hairs in lateral parts; T3-T5 about three-quarters length of T2-T3, with transverse row of long hairs and at lateral margins; ovipositor and sheaths slightly longer than body, sheaths with even covering of long hairs, slightly longer than diameter of sheaths.

Male

Differing from female as follows: Length 2.3-2.6 mm; body generally narrower and more elongate, particularly posterior mesosoma and T1; scape and often proximal one-quarter of antennae brown, legs with same colour pattern but yellower; wings narrower.

Comments

This is a very large genus in Australia of which few species have been described. Primarily, members of

the genus are parasitic on lepidopteran larvae but they have also been recorded from Coleoptera, Diptera and leaf-mining pergid sawflies (Quicke 1988; Quicke & Ingram 1993; Austin & Gauld 1989). Other than one unsubstantiated record of a *Bracon* species being reared from a gall-forming homopteran (Chadwick & Nikitin 1976), this is the first record of an Australian species being reared from a plant gall. Studies on the biology of numerous species overseas and from Australia indicate that all members of the genus are solitary primary ectoparasitoids. Given this, and that *B. fergusoninus* was reared in moderately large numbers from five of seven galls during the project (Table 1), this species is most likely to be parasitic on *Fergusonina* larvae. Previously, Currie (1937) reported rearing an unknown braconid from galls of *Fergusonina* in the Canberra area, and this may be the same species as described here. However, there is apparently no voucher material available from Currie's study in the ANIC or elsewhere. Further, Currie (1937) found this braconid "to feed indiscriminately on gall tissues and fly larvae." We have been unable to confirm Currie's observations but, if this species is a facultative feeder on gall tissue, it will be only the fourth record of phytophagy in the Braconidae in the world (Austin & Dangerfield unpub.), and the first for the subfamily Braconinae.

Bracon fergusoninus differs from other described Australian *Bracon* species in the form of the medial propodeum, shape of T1, sculpturing on T2, length of the ovipositor, and its colour pattern. It is easily identified from other parasitoids associated with *Fergusonina*/*Fergusobia* galls by its complete wing venation (Fig. 7), circular and depressed (cyclostome) clypeus (Fig. 8), elongate ovipositor (Fig. 6), and orange and black colour pattern.

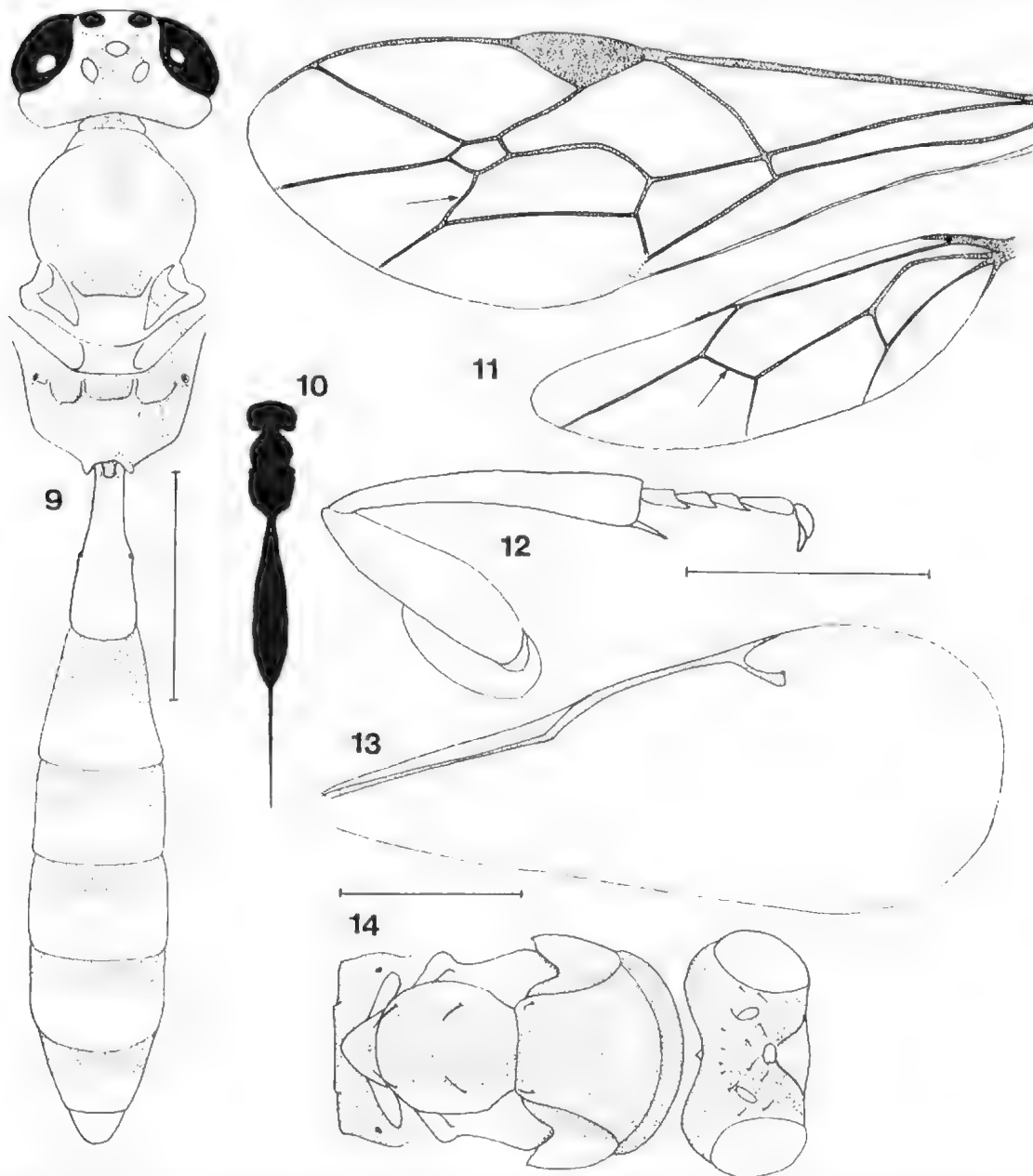
Family Ichneumonidae *Poecilocryptus* spp. (FIGS 9-11)

This genus belongs to an unusual subfamily, the Laberinae, in that it represents one of the most plesiomorphic groups of ichneumonids and has a Gondwanan distribution (Gauld 1983, 1984; Gauld & Holloway 1986). *Poecilocryptus* has been postulated to be phytophagous on the basis of the structure of the mandible (Short 1978) and it has previously been reared from galls on *Acacia* and *Eucalyptus* (Gauld & Holloway 1986) and, more recently, from *Banksia* (Austin & Dangerfield

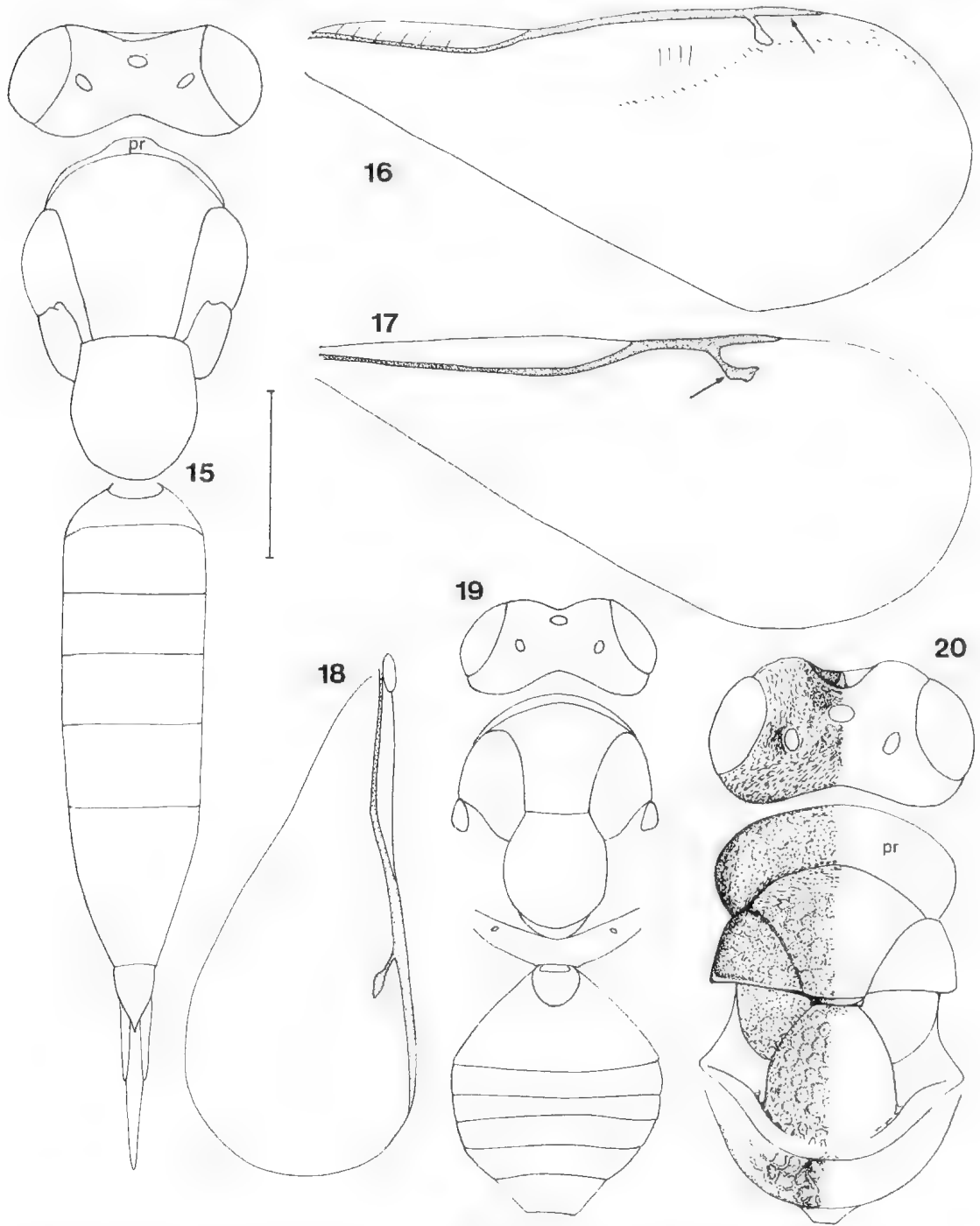
Figs 5-8. *Bracon fergusoninus* sp. nov. 5. Dorsal habitus (not showing ovipositor). 6. Silhouette of dorsal body showing length of ovipositor. 7. Fore and hind wings (vein r-m arrowed in hind wing). 8. Anterior view of head showing circular clypeus. Scale bars 0.5 mm 5; 1.0 mm 7; 0.5 mm 8.

unpub.). However, only very few specimens have ever been reared, as is the case here (i.e. six specimens from four galls - Table 1), indicating that the genus is more likely to be a parasitoid or inquiline than a primary gall-former. Surprisingly, two of the four known species of *Poecilocryptus*, *P. nigromaculatus* Cameron and *P. galliphagus* Gauld

& Holloway, are here associated with *Fergussonina/Fergusobia* galls. Both species have previously been collected from the eastern part of the continent, Queensland to Tasmania, but both are recorded here from South Australia for the first time. *Poecilocryptus nigromaculatus* has been reared from anthribid and chalcid galls on *Acacia longifolia* and eriococcid



Figs 9-14. 9-11. *Poecilocryptus nigromaculatus* Cameron. 9. Dorsal habitus, ♂ (extent of black markings indicated by stippling). 10. Silhouette of dorsal body of ♀ showing length of ovipositor. 11. Fore and hind wings of ♂ (vein 2mcu arrowed in fore wing and vein r-m arrowed in hind wing). 12-14. *Cirrospilus* sp. ♀. 12. Hind leg. 13. Fore wing. 14. Dorsal head and mesosoma (extent of metallic green markings indicated by stippling). Scale bars = 1.25 mm 9, 11; 0.5 mm 12-14.



Figs 15-20. 15, 16, *Euderus* sp. ♀. 15. Dorsal habitus (pr = pronotum). 16. Fore wing (postmarginal vein arrowed). 17, 20, *Eurytoma* sp. 17. Fore wing (stigmal vein arrowed). 20. Dorsal head and mesosoma (pr = pronotum). 18, 19, *Pediobius* sp. ♀. 18. Fore wing. 19. Dorsal head and mesosoma. Scale bar = 0.5 mm.

galls on *Eucalyptus*, while *P. galliphagus* has been associated with unknown galls on *E. delegatensis* and *E. pauciflora* (Gauld & Holloway 1986). *Poecilotheryptus* spp. are distinctive compared with other parasitoids in the guild because of their large size (approximately 10 mm excluding ovipositor) and wing venation (Fig. 11). Although the two species are very similar to each other, they can be separated by the colour of the hind femur and length of the ovipositor.

Family Eulophidae
Cirrospilus sp.
(FIGS 12-14)

Members of this very large and taxonomically difficult cosmopolitan genus are relatively small in size and are often brightly coloured with metallic markings, as is the species here. Different species have been reared as primary parasitoids or as facultative or obligate hyperparasitoids from leaf-mining and gall-forming insects. Thunbert and Austin (1994) recorded four species associated with the mines of *Phyllocnistophaga* on eucalypts in South Australia which, in the case of the dominant species, *C. marginiventris* Girault, was shown to be a facultative hyperparasitoid of *Bracon* and other chalcidoids. The biology of the species here is unclear and it could be either a primary parasitoid on *Fergusonina* larvae or facultatively hyperparasitic on one or more of the gall-associated Hymenoptera. It was the most abundant parasitoid encountered during the study and it was recorded from all seven galls (Table 1). The species is close to *C. occipitis* Girault but differs in the colour pattern of the dorsal mesosoma, and thus may represent a new species. Within the parasitoid guild associated with *Fergusonina*/*Fergusobia* galls, it can be easily identified based on the form of the fore wing venation (Fig. 13), colour pattern and shape of the body (Fig. 14).

Euderus sp.
(FIGS 15, 16)

Like *Cirrospilus*, this is a large genus whose members are difficult to identify. Extralimital host records indicate that *Euderus* are parasitoids of lepidopteran larvae or are hyperparasitoids, particularly of Braconidae (Bouček 1988). The association of the species reared here from *Fergusonina*/*Fergusobia* galls is the first biological information recorded for the genus in Australasia. Given that species overseas have been reared from Braconidae, it is possible that this species is hyperparasitic on *B. fergusoninus*. This proposal is

supported at least in part by the fact that *Euderus* sp. was reared from galls that also yielded individuals of *B. fergusoninus* (Table 1), and that no other hymenopterans in the same galls are large enough in body size to provide sufficient food for the development of *Euderus* larvae (with the exception of *Poecilotheryptus* which was too rare). In the parasitoid guild associated with *Fergusonina*/*Fergusobia* galls, *Euderus* sp. is easily separated from other species by its metallic blue-green colour, elongate body (Fig. 15), mesosoma with very fine reticulate-punctate sculpturing and fore wing with postmarginal vein about as long as stigmal vein (Fig. 16).

Pedihobius sp.
(FIGS 18, 19)

Members of this genus are known to be primary and hyperparasitoids of eggs, pupae and sometimes larvae of various insects, mainly Lepidoptera, Coleoptera, Diptera and Hymenoptera (Bouček 1988). Several species have been reared from leaf-feeding insects on eucalypts (e.g., *Uraba lugens* Walker and *Phyllocnistophaga fringanti* Riek - Austin & Allen 1989; Thunbert & Austin 1994) and various leaf-mining Diptera (Bouček 1988), but apparently none has been reared from gall-associated hosts. The species here was recorded by only a single specimen (Table 1). Although its biology is not known, this very low abundance would indicate that it is probably a hyperparasitoid on another hymenopteran in the *Fergusonina*/*Fergusobia* guild. *Pedihobius* sp. can be easily separated from the other parasitoids recorded by its relatively short compact body (Fig. 19), black colour, very finely reticulate dorsal mesosoma, and elongate postmarginal vein (Fig. 18).

Family Eurytomidae
Eurytoma spp.
(FIGS 17, 20)

This is a very large genus in Australia containing species with divergent biologies. Species can be phytophagous, facultatively parasitic, obligatorily parasitic or hyperparasitic (Bouček 1988). In Australia, the majority of species are postulated to fall into the latter two categories, but the generic classification is not well understood and species belonging to apparently closely related genera and/or species groups are known to be either phytophagous or parasitic. A number is known to be ectoparasitic on gall-forming insects or hyperparasitic through ichneumonid and braconid cocoons (Bouček 1988). Currie (1937) reported one species of *Eurytoma*, *E. "varirufipes"*, to be phytophagous in *Fergusonina* galls near Canberra (*varirufipes* is an unpublished

manuscript name - see Dahms (1986; Bouček 1988). Unfortunately, we have not been able to confirm the biology of the species encountered in this study by direct observation. One of them (see below) may be the same species as recorded by Currie (N.B. no voucher material is available from his study) and therefore possibly be phytophagous (see Discussion), or they could be different species and be parasitic on *Fergusonina* larvae or on one of the other hymenopterans in the guild, possibly *B. fergusoninus* sp. nov. The species here was recorded from all the galls surveyed and was the third most abundant hymenopterum in the *Fergusonina*/*Fergusobia* guild (Table 1).

Euclyptus often display intraspecific morphological variability and are therefore difficult to separate at the species level. The material reared here varies slightly in size, colour, pilosity and sculpturing and may represent more than one species. The genus can be easily separated from other parasitoids in the guild based on the shape of the pronotum, dorsal sculpturing pattern (Fig. 20), and wing venation (Fig. 17). The sexes are highly dimorphic with males being smaller, having a disproportionately smaller metasoma, and asymmetrical pilose antennae.

Family Pteromalidae

Coeloclyba nigrocineta Ashmead (FIGS 23, 24)

This species and all members of the genus are probably inquiline of hymenopterum and dipteran gall-formers on *Acacia* and *Eucalyptus* (Bouček 1988). Previously, *C. nigrocineta* has been reared from the galls of the phytophagous pteromalids *Trichilogaster* and *Perilampella* (Noble 1940, 1941) and, in the latter case, has been proved to be an inquiline, i.e., it kills the resident cecidogenic wasp and forms its own cells to feed on the gall tissue. The species was originally described from material reared from "agromyzid galls on *Eucalyptus corymbosa*" (identified by Bouček (1988) as *Fergusonina* galls) in Sydney (Asluncad 1900), and was subsequently recorded from *Fergusonina*/*Fergusobia* galls as an obligate parasitoid in the Canberra area by Currie (1937). Specimens in ANIC were collected from galls on *E. camaldulensis* at Alice Springs, NT and *E. vicentii* L. Johnson and *E. amygdalina* Labill. at Bichen, Tas. (I. D. Naumann pers. comm.). We have been unable to confirm its biology in this study, but clearly it is most likely to be an inquiline or primary parasitoid of *Fergusonina*. *Coeloclyba nigrocineta* was reared only in moderate numbers here but it was recorded from five of the seven galls surveyed (Table 1). It is apparently distributed along the east coast of Australia from north Queensland to Tasmania, but this seems to be the first record of the species from South Australia.

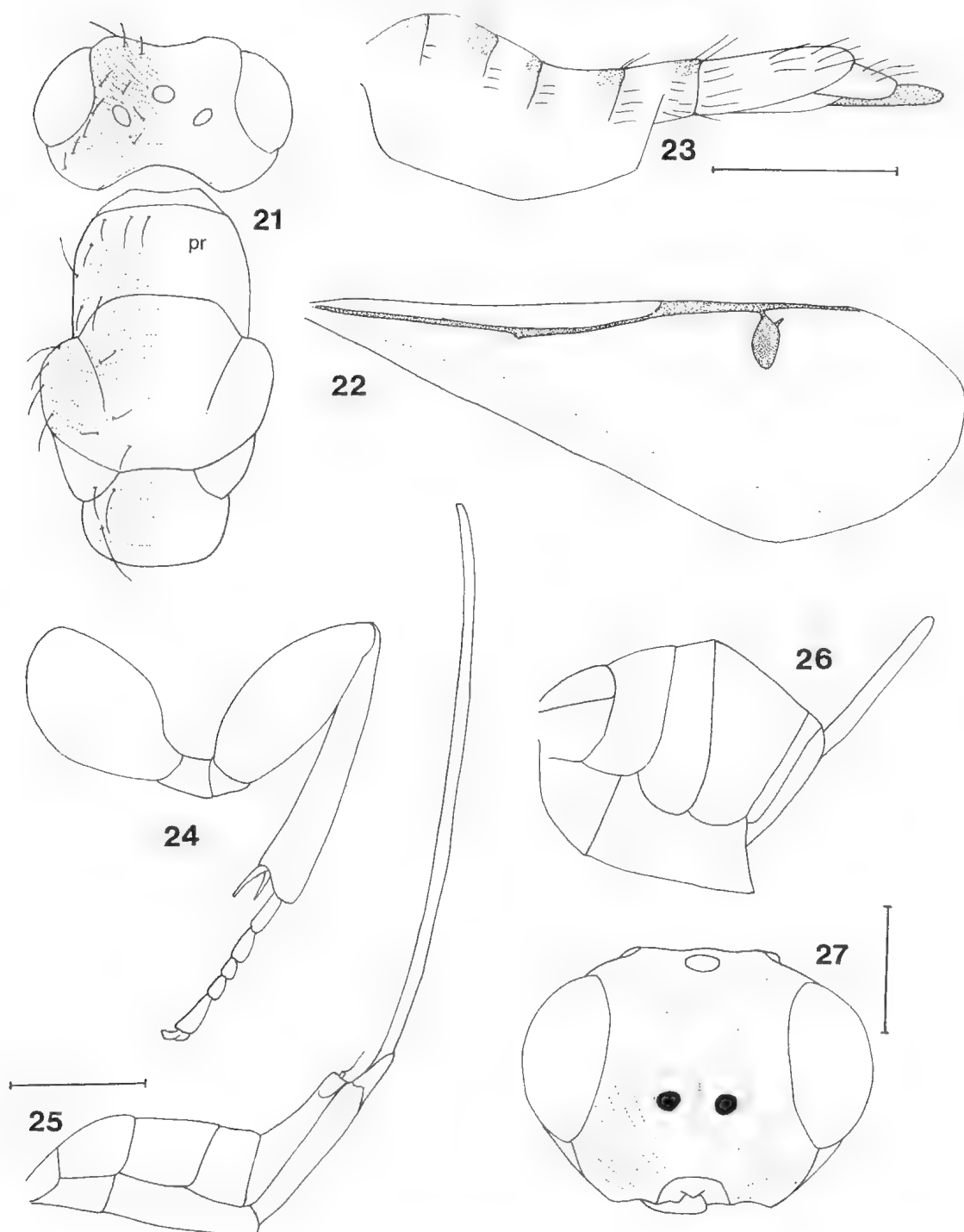
Coeloclyba nigrocineta can be easily separated from other parasitoids associated with *Fergusonina*/*Fergusobia* galls by its elongate stigmal vein, short ovipositor and distinctive bright yellow body and metasoma with black transverse stripes (Fig. 23).

Ditropinella sp. (FIG. 26)

Members of this genus have previously been treated under the Tuiyidae or as miscogasterine pteromalids, but most recently they have been placed in their own subfamily, Ditropinellinae, within the Pteromalidae (Bouček 1988). Previously, they have been reared from *Apiomorpha* galls on *Eucalyptus* and unknown galls on *Eucalyptus*, *Acacia*, *Casuarina* (Bouček 1988) and a number of other plants. The biology of the genus is poorly known. However Currie (1937) reported *D. compressiventris* Girault to be phytophagous within *Fergusonina*/*Fergusobia* galls in the Canberra area. During this study, only nine individuals were reared from three galls (Table 1) and, based on these numbers, the species is more likely to be an inquiline or parasitic on one or more gall inhabitants. We have not been able positively to identify the species here as *D. compressiventris*, primarily due to morphological variability among species in the genus (Bouček 1988). However, it can be easily distinguished from the other parasitoids in the guild by its bright metallic green body, laterally compressed metasoma, and exerted ovipositor (Fig. 26).

Family Tuiyidae *Megastigmus* spp. (FIGS 21, 22, 25)

The Megastigminae are best characterised by their large, knob-like fore wing stigma and elongate ovipositor of the female. The genus *Megastigmus* is large and taxonomically difficult in Australia, with more than 40 described species. As well, its members have diverse biologies in that apparently closely related species can be phytophagous, cecidogenic, inquiline or parasitic, although the detailed biology of no Australian species has been confirmed (Bouček 1988). Various species have been reared from dipteran galls on *Asterantolostus*, *Apiomorpha* (Eriococcidae) on *Eucalyptus*, *Bruchophagus* (Eurytomidae) galls on *Eremocitrus*, *Trichilogaster* (Pteromalidae) galls on *Acacia*, as well as unknown galls on numerous native plants (Bouček 1988). Two species, *M. quinquesetae* Girault and *Megastigmus* sp., were reared from *Fergusonina*/*Fergusobia* galls in the Canberra area by Currie (1937), and were reported by him to be phytophagous. We have been unable to confirm Currie's identification of these species, or to show



Figs 21-27. 21, 22, 25, *Megastigmus* sp. ♀. 21, Dorsal head and mesosoma (pr = pronotum). 22, Fore wing. 25, Lateral view of metasoma and ovipositor. 23, 24, *Coelocyba nigrocincta* Ashmead ♀. 23, Lateral view of metasoma (extent of black markings indicated by stippling). 24, Hind leg. 26, *Ditropinotella* sp. ♀. Lateral view of metasoma and ovipositor. 27, *Bootanellus* sp. ♀. Anterior view of head. Scale bars = 0.5 mm 21-26; 0.25 mm 27.

that they are indeed phytophagous. The number of individuals obtained for the two species reared here was pooled because of initial problems in separating them taxonomically. Combined, they were reared from all seven galls surveyed and occurred in large numbers (Table 1), being the second most abundant genus present in the guild.

Megastigmus can be easily distinguished from the other *Fergusonina*/*Fergusobia* gall-inhabiting Hymenoptera by their spot-like fore wing stigma (Fig. 23), bright yellow colour with some dark markings, and the length of the ovipositor (Fig. 25). From each other they can be separated by the colour of the metasoma. The metasoma of one species is mostly dark whereas in the other it is yellow with transverse black stripes.

Boutanellus sp.
(FIG. 27)

This is a moderate-sized genus of megastigmines characterised by the presence of a medial tooth on the lower clypeal margin and some metallic coloration. There are 20 described species in Australia of which three have been previously associated with seeds of *Casuarina* and galls on *Citrus* and *Micromelus* (Bouček 1988). The biology of the species reared here from *Fergusonina*/*Fergusobia* galls is unknown, but it was reared in moderate numbers from three of the seven galls examined (Table 1). Based on these numbers and the fact that it emerged well after all other gall inhabitants, this species is most probably a parasitoid or inquiline. The species is very striking and easy to separate from the other Hymenoptera associated with *Fergusonina*/*Fergusobia* galls based on its yellow body with bright metallic green dorsal head and mesosoma, black dorsal metasoma and clypeus with a medial tooth (Fig. 27).

**Key to the parasitoids reared from
Fergusonina/*Fergusobia* Galls
in South Australia**

1. Fore wing with more than one enclosed cell, moderately complete venation (Figs 7, 11); prepectus absent (Ichneumonidae) 2
2. Fore wing with no more than one enclosed cell, venation restricted to anterior margin of wing (Figs 13, 16, 22); prepectus present (Chalcidoidea) 4
2. Fore wing with vein 2m-cu present; hind wing with vein r-m meeting Rs after Rs diverges from Sc+R (Fig. 11) (Ichneumonidae) [length about 10 mm without ovipositor; ovipositor shorter than metasoma (Fig. 10); clypeus normal; body orange-yellow with black stripes on metasoma and hind legs (Fig. 9)] (*Poecilovryptus*) 3

Fore wing with vein 2m-cu absent; hind wing with vein r-m meeting Rs before Rs diverges from Sc+R (Fig. 7) (Braconidae) [length about 2.5 mm without ovipositor; ovipositor almost as long as body (Fig. 6); clypeus circular and depressed (Fig. 8); orange in colour with posterior mesosoma and metasoma black]
..... *Bracon fergusoninus* sp. nov.

3. Hind coxa black; ovipositor about 2.5 x length of hind tibia *P. nigromaculatus* Cameron
- Hind coxa yellow; ovipositor about 2.2 x length of hind tibia
..... *P. galliphagus* Gauld & Holloway
4. In dorsal view, pronotum large and sub-rectangular or broadly rounded (Figs 20, 21) 5
- In dorsal view, pronotum narrow and comprising little if any of dorsal surface of mesosoma (Figs 15, 19) 8
5. Fore wing with elongate stigmal vein (Fig. 17) (Eurytomidae) [body all black, legs often brown or orange-brown distally; female with dorsal mesosoma coarsely reticulate-punctate (Fig. 20), ovipositor short and virtually hidden under metasoma] *Eurytoma* spp.
- Fore wing with large spot-like stigmal vein (Fig. 22); female with elongate exposed ovipositor (Fig. 25) (Torymidae) 6
6. Body all yellow with some dark markings; clypeus without a medial tooth (*Megastigmus*) 7
- Ventral and lateral surfaces of body yellow, dorsal head and metasoma bright metallic green, dorsal metasoma black; clypeus with medial tooth (Fig. 27) *Boutanellus* sp.
7. Metasoma mostly dark dorsally, stripes or striped pattern indistinct *Megastigmus* sp. 1
- Metasoma yellow with transverse black stripes *Megastigmus* sp. 2
8. Hind tarsi 5-segmented (Fig. 24) (Pteromalidae) 9
9. Hind tarsi 4-segmented (Fig. 12) (Eulophidae) 10
9. Body bright yellow or yellow-brown, metasoma depressed, with broad black transverse stripes dorsally; ovipositor short, hardly protruding from posterior metasoma (Fig. 23)
..... *Cuclocyba nigrocincta* Ashmead
- Body bright metallic green; metasoma compressed; ovipositor exerted posteriorly (Fig. 26) *Ditropinotellus* sp.
10. Body with distinct bright colour pattern, including metallic green markings on dorsal mesosoma (Fig. 14) and black transverse stripes on metasoma *Circospilus* sp.
- Body with uniform dark colour 11

- 1). Body elongate (Fig. 15), metallic blue-green in colour; dorsal mesosoma with very fine reticulate-punctate sculpturing; fore wing with postmarginal vein about as long as stigmal vein (Fig. 16), *Euderus* sp.
 Body relatively short, compact (Fig. 19) and black in colour; dorsal mesosoma with very fine reticulate sculpturing; fore wing with postmarginal vein much longer than stigmal vein (Fig. 18), *Pediobius* sp.

Discussion

The mechanisms by which the host plant cells are induced to proliferate to form a gall remain problematic. Currie (1937) observed that nematodes were actively feeding and causing cell proliferation of plant tissue around the eggs of the fly before they hatched. This suggests that juvenile nematodes are responsible for gall initiation (presumably via salivary secretions). It is not inconceivable, however, that a fraction of oviposition fluid which is injected into the plant by the fly along with the eggs, or mechanical damage by the ovipositor alone, also causes cell proliferation. It has been observed with other *Fergusonina*/*Fergusonia* associations (Davies unpub.) that galls in which fly larvae have died, but in which nematodes are still present, remain green and viable; Currie (1937) reported that when infertile fly eggs were deposited, galls were initiated, but were 'aborted at an early stage' while the nematodes persisted for some months but eventually died out. He suggested that further gall growth was attributable to fly larvae. Whatever the mechanism, gall growth for *E. flavicornis* was particularly rapid in that galls attained full size in a matter of weeks during the late summer generation.

While no faecal material was observed in gall cavities of *E. flavicornis*, Currie (1937) observed that faeces were 'practically absent' in all but one species of *Fergusonina*. He postulated that nematodes, which by then occur within the fly cavity, feed on fly faeces thus keeping the cavity free of waste. Given the strong stylet of the nematodes, it is more likely that they feed on plant cells. Microscopic examination of specimens cleared in glycerol indicated the presence of a rectum and anus in *E. flavicornis* larvae. It is possible, however, that larvae may store, or produce minimal amounts of excretory products to avoid fouling the cavity. If this is so, it suggests an adaptation similar to that found in the gall-forming Cecidomyiidae (Diptera), the larvae of at least some of which possess a functional anus but produce no noticeable waste products (Gagné 1989). Perhaps related to the storage of waste, *Fergusonina* puparia were observed anchored within the gall cavity by means of a gelatinous substance at the posterior end. It is conceivable that this

substance represents digestive waste voided just prior to pupation. Unlike some cecidomyiid galls (Gagné 1989), fungal colonisation of fresh *Fergusonina* galls was not observed. The fly larvae may use the dorsal shield, with its anteriorly directed prongs, to scrape the observed pellets of plant material from the wall of the cavity. Currie (1937) described third instar fly larvae as 'tearing down' inner layers of the cavities for food. The shield may also be used to anchor the larvae in one spot within the cavity and to break down parts of the cavity walls prior to pupation to facilitate emergence of the adult fly.

It is unclear how adult flies escape from the galls after emerging from puparia. Dissection of galls revealed that by the time of pupation, cavities on the edges of the gall were separated from the outside only by a thin layer of epidermal cells, suggesting that the larvae tunnel near to the surface prior to pupation. Presumably, adult flies are able to emerge through this thin layer relatively easily. Cavities deeper in the mature gall are separated by thin layers of parenchymatous tissue and sometimes open into each other.

The 12 species of Hymenoptera reared from leaf galls of *E. flavicornis* during this study represent twice the number previously recorded from *Fergusonina* galls. Currie (1937) reared only six species from flower galls in the Canberra area, while Harris (1982) recorded four species from *Fergusonina* galls in India. Further, several species are here associated with *Fergusonina* galls for the first time, viz., *Boanellus* sp., *Cirrospilus* sp., *Euderus* sp., *Pediobius* sp., and (two species of) *Poecilochrysis* (*P. nigromaculatus* and *P. galliphagus*). Although the composition of hymenopterian species associated with individual galls clearly differs, the most common species encountered in this study, *Cirrospilus* sp., *Eurytoma* spp. and *Megastigmus* spp., were reared from all galls (Table 1), while *B. fergusoninus*, *C. nigricinctus* and *Euderus* sp. were reared from more than 70% of galls. The difference in the size of the hymenopterian guild between this study and that of Currie (1937) may be attributable to differences in the structure and position of galls, i.e., *E. flavicornis* forms leaf galls while the species studied by Currie formed bud galls. Also, the fact that galls were caged in the field during this study means that all Hymenoptera were collected, whether they were common or rare. To assess the composition of wasp species by dissecting galls, as apparently undertaken by Currie for at least part of his study, is likely to lead to an under-estimation of the true number present. Such dissections mostly reveal larval stages that are often difficult to identify; they are soft-bodied and therefore are easily damaged and there is a greater chance of overlooking rare species.

The leaf galls caused by *E. flavicornis* appear, on

dissection, to have a relatively homogeneous matrix and, although some woody tissue is apparent, the most important mortality agent is likely to be parasitic wasps, given that as many individuals of Hymenoptera as *E. flavicornis* were reared from galls (although not all species are necessarily parasitic - see above). However, Currie (1937) attributed up to 60% of *Fergusonina* mortality in bud galls to the inability of fly larvae, prior to pupation, to tunnel through the woody gall tissue induced by hymenopterianinquilines, resulting in their entombment within the gall. He reported that wasp inquilines were found mainly within the outer surface of bud galls, but fly larvae deeper in the gall were largely free of parasites. He also reported that approximately the same number of wasps and flies emerged from leaf galls on *E. Stuartiana* (V.M. (sic), and suggested that there is a higher level of parasitism in stem tip and leaf tip galls than in flower bud galls.

It is clear from this study and as reported elsewhere (e.g. Bouček 1988; Gough & McMahon 1988) that it is very difficult to determine the biology of gall-associated Hymenoptera. Primarily, this is because their pre-adult stages are hidden within the gall, their biology may change from one stage to another (as in the case of inquilines which may kill the resident gall-former and then become phytophagous), or it may be different from related species that do not inhabit galls. It is therefore naive to assume biological traits for gall-associated wasps by

extrapolating from other species or indirect information such as emergence time and/or number of individuals present. For such species, their biology may be determined only by direct and detailed observations including their morphology and life history. In this respect, we have been unable to confirm the biology of any species reared in this study, although we speculate above on what some of these species may be doing, as a means of stimulating further study. The comments made by Currie (1937) that the species of *Ditropinotella*, *Megastigmus* and *Eurytoma* he recorded from *Fergusonina* bud galls are phytophagous must be treated with some caution, given that he presents little or no evidence to support this conclusion, and at least the latter two genera are known to contain species which are either phytophagous or parasitic. Further, his reporting that *C. nigrocinerea* is a "true parasite" and that the unknown braconid (probably *Bracon*) he reared was an inquiline is inconsistent with previous studies on these taxa (see above).

Acknowledgments

We wish to thank John LaSalle, Eric Grissell, and David Wahl for assistance with identifying some of the parasitoid species, Peter Cranston for identifying *E. flavicornis*, Peter Kolesik for useful discussions and Paul Dangerfield for the line drawings. We thank Lee Hallet for access to the field site.

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**STUDIES ON THE SOIL-INHABITING TARDIGRADE,
MACROBIOTUS CF. PSEUDOHUFELANDI,
FROM SOUTH AUSTRALIA**

*BY ALAN F. BIRD**

Summary

Bird, A. F. (1996) Studies on the soil-inhabiting tardigrade, *Macrobiotus* cf. *Pseudohufelandi*, from South Australia. *Trans. R. Soc. S. Aust.* 120(4), 147-154, 29 November, 1996.

A tardigrade isolated from agricultural soils at Avon is the first member of this phylum to be described from South Australia. Specimens were isolated from freshly-collected soils and from soil that had been stored dry for three years.

Live and fixed specimens were examined under the light microscope and fixed, stained and gold-coated specimens were examined using the scanning electron microscope.

Key Words: *Macrobiotus* cf. *pseudohufelandi*, anhydrobiosis, microscopy, tardigrades, birefringence, biocontrol.

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Live and fixed specimens were examined under the light microscope and fixed, stained and gold-coated specimens were examined using the scanning electron microscope.

This tardigrade, a stout cylindrical organism about 500 µm long by 150 µm wide with the four pairs of stubby legs ending in paired claws, has been assigned to the species *Macrobotus* cf. *pseudohufelandi* on the basis of the morphology of the buccopharyngeal apparatus, claw shapes and egg processes. The stylets are slightly curved, sabre-shaped structures about 40 µm in length and exhibit marked birefringence under polarized light. When these tardigrades are killed the stylets break down and disappear.

A specimen of *M.* cf. *pseudohufelandi* was observed feeding on a nematode and a significant decrease in the number of nematodes in the soil as the number of tardigrades increases has been demonstrated.

KEY WORDS: *Macrobotus* cf. *pseudohufelandi*, anhydrobiosis, microscopy, tardigrades, birefringence, biocoulter

Introduction

The tardigrades or water bears belong to a discrete phylum, Tardigrada, of cosmopolitan distribution from diverse habitats including marine, fresh water and terrestrial environments. The majority are thought to live in water films surrounding the "leaves" of mosses and lichens. They are microscopic (with adults commonly ranging in length from 200 - 500 µm), are plump and cylindrical in shape and have four pairs of stubby legs ending in claws. They may or may not have eye spots.

In Australia tardigrades have been recorded from Queensland, New South Wales, Victoria, Western Australia and Tasmania but not from South Australia (McInnes 1994).

In this paper I report upon the morphology and some aspects of the behaviour of a tardigrade isolated from agricultural sandy loam soil from Avon, South Australia.

Materials and Methods

Locality and soil type

The tardigrades were isolated from a soil of sandy loam texture classified as a solonized brown earth (Australian soil grouping) or as an entisol (US soil classification). The locality was an experimental plot on a farm at Avon (latitude 34° 14' S, longitude 138° 19' E) which was direct drilled and had a wheat/wheat rotation.

Soil cores (diam. 5 cm, depth 10 cm) were collected and mixed in a plastic bag. The sample mostly used in these experiments was collected in July 1993 and had been stored dry at room temperature for three years. However, freshly-collected soil from the same site on 29. iii. 1996 prior to the autumn rains was also used for comparison.

Extraction from soil

After thorough mixing of the soil, 50 g aliquots were placed in a misting apparatus for three days (Yeates & Bird 1994). This procedure was replicated in quadruplicate and, after three days, the collecting tubes were removed and their contents allowed to settle for 1 h after which the supernatant was removed by suction to within 2.5 cm of the bottom of the tube. This extraction procedure was used for all soils, whether freshly-collected or stored.

Counting

The contents of each tube were poured, after vigorous shaking, into a counting chamber (Daneaster 1962). The tardigrades gravitated to the floor of the counting chamber between the rings and were counted under a dissecting microscope.

Light microscopy

The tardigrades were examined under bright field, polarized light and differential interference contrast (Nomarski) optics using a Vanox Olympus AHB-T research microscope.

Living tardigrades were examined in distilled water under a coverslip sealed at its edges with nail varnish.

* 2 Playford Road Mitcham S. Aust. 5062.

Specimens were fixed by adding an equal volume of boiling double strength FA 4:1 (20 ml 40% formaldehyde and 2 ml glacial acetic acid in 78 ml distilled water) in a test tube to a shaken suspension of the tardigrades in distilled water, also in a test tube. These specimens were processed to pure glycerol by Seinhorst's (1959) method and mounted in anhydrous glycerol on slides sealed to a coverslip by molten paraffin as described by De Maeseneer & D'Herde (1963) and then ringed with Entellan (Merck). Both living and fixed material were photographed using Ilford Delta 400 film.

Scanning electron microscopy

For observations under the scanning electron microscope (SEM), the fixed material was washed repeatedly in distilled water, post-fixed and stained in 1% aqueous osmium tetroxide, washed repeatedly again in distilled water, immersed in filtered freshly-made saturated aqueous thiocarbonylhydrazide for 30 min followed by repeated washings in distilled water and a repetition of the osmium fixation. This osmium-binding technique (Kelley *et al.* 1973) was followed by further washings in distilled water.

Specimens were freeze-dried by placing them between membrane filters which were frozen rapidly by placing them in a slurry of freon cooled by liquid nitrogen. The filters with attached tardigrades were then transferred rapidly to a freeze drying machine and freeze-dried at -70°C over a period of three days. This dried material was then mounted on a glass coverslip attached to an SEM stub and coated with 30 nm of gold to enhance stability and conductivity. The material was then examined and photographed in a Cambridge S 250 Mk 3 SEM operated at 20 kV using Ilford 120 roll film (FP4 Plus).

Feeding experiments

Attempts to determine whether or not *M. cf.*

pseudohufelandi would feed on *Rhizoctonia solani*, and thus possibly implicating the tardigrade in suppression of this plant pathogen in the field, were made using *R. solani* grown in culture media in Petri dishes. Specimens of *M. cf. pseudohufelandi* that had been washed repeatedly in sterile distilled water by centrifugation in an effort to surface sterilize them, were poured on to the fungal plates under aseptic conditions in a laminar flow cabinet.

Results

Morphology

Both living and fixed specimens of the tardigrade isolated from the Avon soil were examined and measured. Measurements of the lengths and widths of ten specimens each of fixed and living material showed, as might be expected, that some shrinkage had occurred in the fixed material. Measurements of the living material were made only on specimens that had their tips and mouth parts retracted since this was the state observed in all fixed or dead material. The mean length of living specimens was $511.4 \pm 47.7 \mu\text{m}$ (range 428–580 μm , Table 1) and that of fixed material was $423.2 \pm 48.3 \mu\text{m}$ (range 364–500 μm). Similarly, the width of the living specimens was $154.7 \pm 15.3 \mu\text{m}$ (range 128–172 μm , Table 1) compared with $131.2 \pm 13.3 \mu\text{m}$ (range 108–148 μm).

The lateral view of the living tardigrade with its mouth everted and showing one of each of the four pairs of stubby legs ending in claws (Fig. 1) together with the characteristic internal structure of the anterior region (Fig. 2) and the claws at the extremities of the fourth pair of legs (Figs 3, 4) are shown as viewed under the light microscope.

The fixed tardigrade in ventro-lateral view with the mouth region inverted but showing all four pairs of legs with their claws (Fig. 5) and the ultrastructure of the claws on the second leg (Fig. 6) are shown as viewed under the SEM.

TABLE 1. Measurements of living *Macrobrotus cf. pseudohufelandi*

Part measured (μm)	Numbers measured	Mean	S D	Range
Length of whole specimen	10	511.4	± 47.7	428–580
Width of whole specimen	10	154.7	± 15.3	128–172
% position of stylet				
support on buccal tube	8	81.0	± 1.3	79.5–82.5
Length of buccal tube	8	40.25	± 1.2	39–42
Width of buccal tube	8	5.1	± 0.2	5–5.5
Length of pharyngeal bulb	8	37.4	± 2.1	35–40
Width of pharyngeal bulb	8	34.4	± 1.3	33–36
Length of macroplacoid (1)	8	10.75	± 1.0	9–12
Length of macroplacoid (2)	8	6.0	± 0.5	5–7
Length of microplacoid	8	2.9	± 0.2	2.5–3.0
Length of 1st foot-claw	4	8.25	± 2.9	8–9

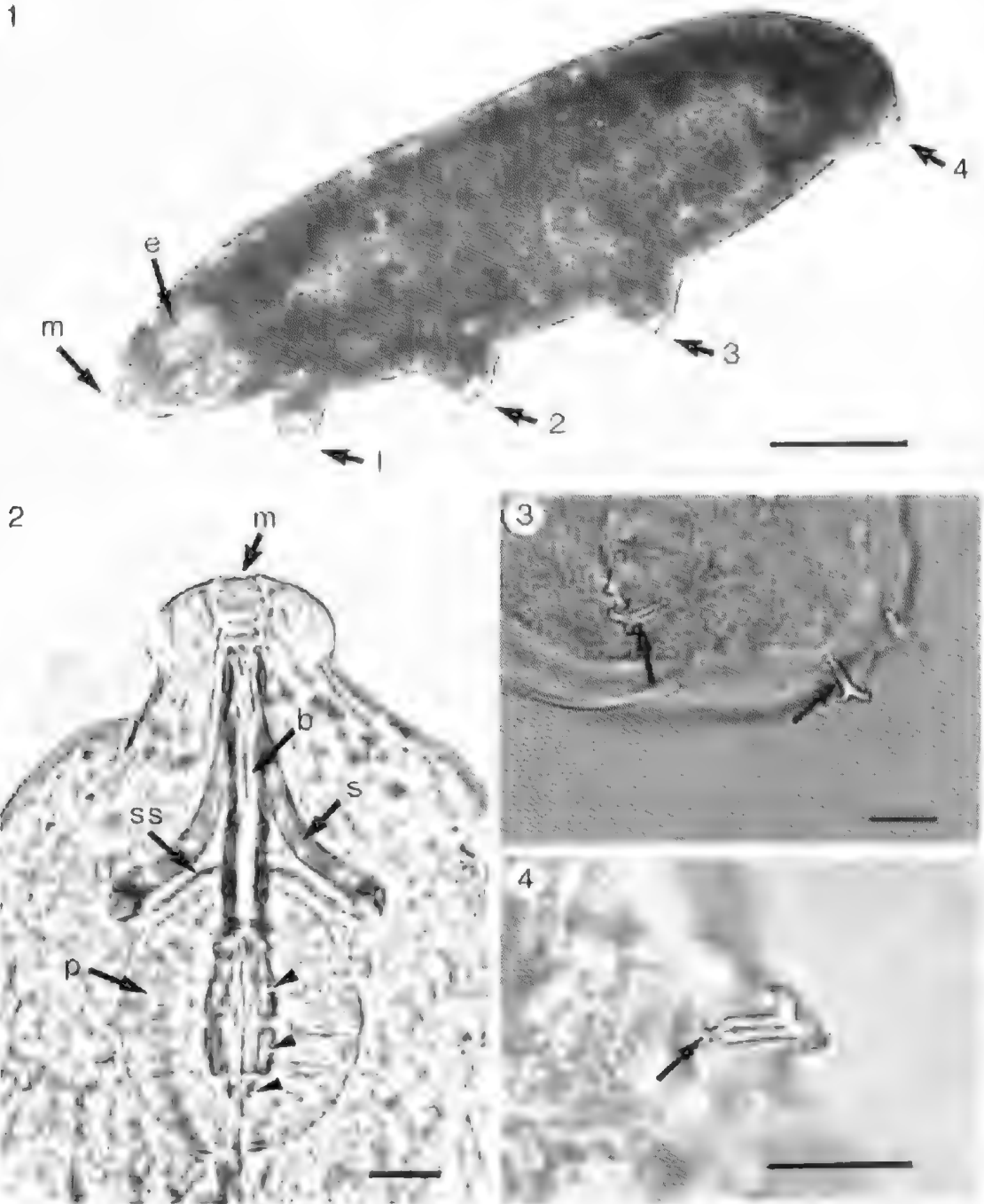


Fig. 1. Whole living *Macrobiotus* cf. *pseudohufelandi*. Bright field optics. Lateral view showing everted sucking mouth (m), eyespot (e) and one of each of the four pairs of legs with terminal claws (arrows labelled 1-4 from front to rear). The fourth leg is posterior and subterminal. Scale bar = 100 μ m.

Fig. 2. Everted head of living *Macrobiotus* cf. *pseudohufelandi*. Bright field optics showing mouth (m), buccal tube (b), stylets (s), stylet support (ss), pharynx (p), macroplacoids 1 & 2 and microplacoids (arrowheads from top to bottom). Scale bar = 10 μ m.

Fig. 3. Posterior region of *Macrobiotus* cf. *pseudohufelandi*. Bright field optics showing claws of the 4th legs (arrows). Scale bar = 10 μ m.

Fig. 4. Single claw from the 4th leg of *Macrobiotus* cf. *pseudohufelandi*. Note basal plate at base of claw (arrow). Scale bar = 10 μ m.



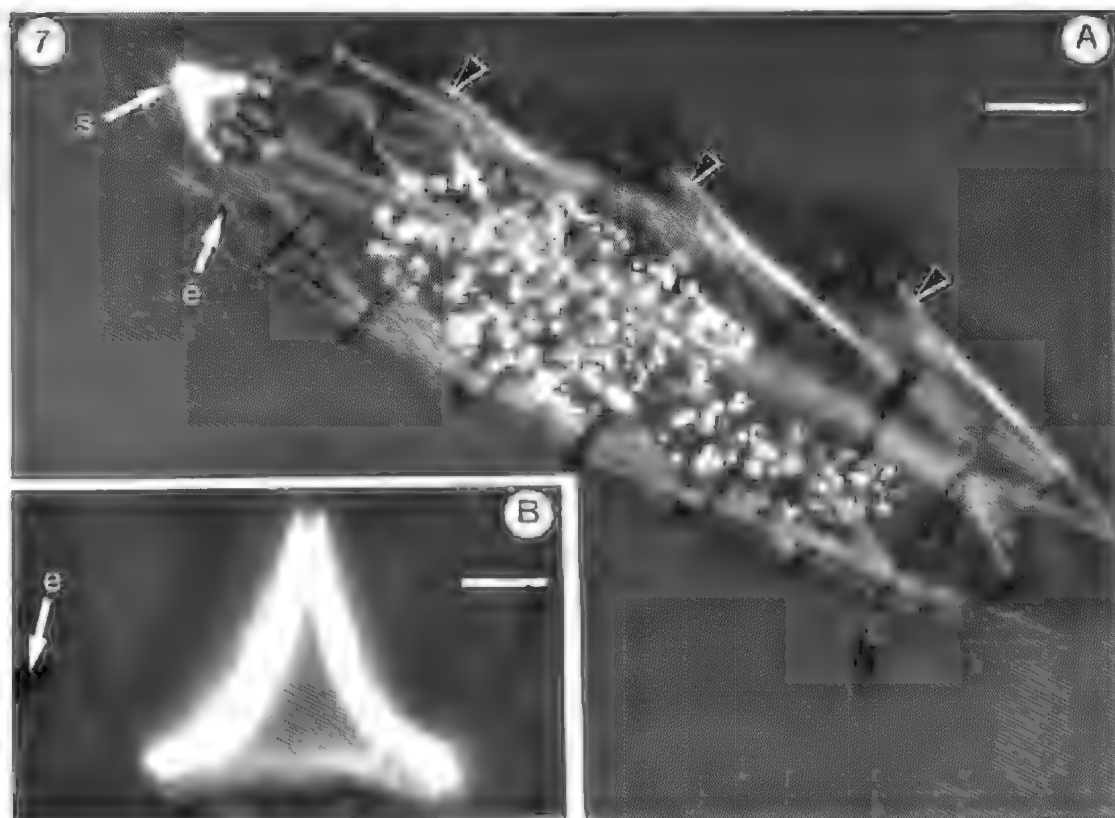


Fig. 7. Living *Macrobrotus* cf. *pseudohufelandti* viewed under polarized light. A. Whole specimen. Note birefringence of stylets (s), gut contents and muscle attachments to legs (arrow heads). One of the two eyes (e) is also shown. B. Inset showing an eye (e) and the pronounced birefringence of the two stylets. Scale bars = 50 μ m A, 10 μ m B.

Although for general purposes bright field optics were found to be more convenient than the other systems used, stylet structure was much more obvious in living tardigrades under Nomarski and polarized light optics than under bright field. Stylets were, however, clearly observed under all three optical systems provided that the tardigrade was alive. In both dead and fixed material, the stylets lose their integrity and appear to break down.

When viewed under polarized light (Fig. 7) the stylets exhibited marked birefringence indicating a regular structural orientation. The stylets are slightly curved, sabre-shaped structures about 40 μ m in length (Figs 2, 7B). When the tardigrades were subjected to oxygen deprivation on sealed slides, the

stylet birefringence gradually disappeared and was entirely lost over a period of several hours as the stylets broke down. Muscles and intestinal contents exhibited birefringence to a lesser extent than the stylets (Fig. 7). However, the muscles and intestinal contents retained their integrity and birefringence after stylet break down. Stylet break down also occurred during fixation which accounts for their absence in camera lucida drawings of fixed material in the literature. Thus stylets can only be observed in living material.

The buccal tube (Fig. 2, Table 1) is 40.25 μ m long \times 5.1 μ m wide (percent ratio to the length of the buccal tube (pt) = 12.67). The stylet supports (Fig. 2, Table 1) are inserted at 81% of the buccal tube

Fig. 5. Whole, fixed and gold-coated specimen of *Macrobrotus* cf. *pseudohufelandti*; SEM photograph showing four pairs of legs with claws (arrows labelled 1-4 from front to rear). Scale bar = 100 μ m.

Fig. 6. SEM photograph of a 2nd leg. Note two sets of double branched claws. The inner branch in each claw carries two accessory points (small arrows). The basal plate at the base of the claw is seen here as a rounded thickening (larger arrow). Scale bar = 4 μ m.

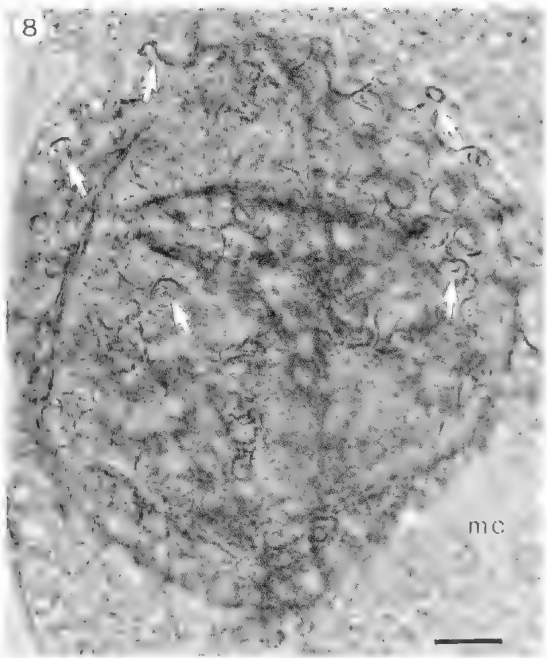


Fig. 8 Crushed egg of *Macrobiotus* cf. *pseudohufelandi* lying within the moulted cuticle (mc). Bright field optics showing the “cooling tower”-shaped projections on the surface of the egg shell (arrows). Scale bar = 10 μ m.

length. The pharyngeal bulb is 37.4 μ m long x 34.4 μ m wide, has apophyses, two pairs of rod-shaped macroplacoids and a pair of microplacoids. The macroplacoids differ in length, the first being 10.75 μ m long (pt = 26.71) and the second 6.0 μ m (pt = 14.91); the microplacoids are 2.9 μ m long (pt = 7.21). The claws (Figs 3, 4, 5, 6, Table 1) have smooth basal plates (Dastych & Alberti 1990) and well-developed accessory points on their inner branches. The length of the fourth foot claw is 8.25 μ m (pt = 20.50). The egg, enveloped by the shed cuticle, (Fig. 8) has numerous “cooling tower”-shaped projections on its surface which protrude about 5 μ m.

Taxonomy

This tardigrade was, using available keys and on comparison of measurements, determined as *Macrobiotus hufelandi* Schultze, 1834. This species is cosmopolitan (Schuster & Grigarick 1965). However, measurements and slides were sent to a tardigrade taxonomist (S. Claxton) who kindly examined the material and considers that this tardigrade most closely resembles *Macrobiotus pseudohufelandi* Iharos, 1966 and should be assigned tentatively to this species (S. Claxton pers. comm.). Accordingly, the Avon tardigrade has been identified as *Macrobiotus* cf. *pseudohufelandi* subject to further deliberations by taxonomists.

Behaviour

Specimens of *M. cf. pseudohufelandi* were placed in Petri dishes containing the plant pathogenic fungus *Rhizoctonia solani*. Although some of the tardigrades lived for several weeks, they were not observed to feed, grow or reproduce on the fungus. Furthermore, no significant differences were observed in the logarithmically transformed numbers of this tardigrade isolated from soil that exhibited suppression of this fungus compared with the tardigrade numbers, logarithmically transformed, isolated from soil that did not exhibit suppression of the fungus ($p < 0.05$) (Table 2). However, there does appear to be a significant inverse linear relationship between the numbers of *M. cf. pseudohufelandi* in the soil and the numbers of nematodes ($p < 0.001$). Furthermore, a specimen has been obtained alive from the soil that was in the process of feeding on a nematode (Fig. 9). In soil that had been stored dry for three years, there was a marked decline in the numbers of nematodes (4 ± 2.9 /50 g soil) compared with the number of tardigrades (34 ± 5.8 /50 g soil).

Discussion

The first recorded observation of a tardigrade was by Goeze (1773) (cited by Nelson & Higgins 1990) who referred to them as “little water bears” (*Kleiner*

TABLE 2. The relationships between tardigrades and nematodes in *Rhizoctonia*-suppressive and *Rhizoctonia*-non-suppressive soils

Soils	Tardigrades	Nematodes	Tardigrades	Nematodes
	Mean counts* SD	Mean counts* SD	log mean counts [†]	log mean counts [†]
Suppressive	19 ± 9.1	401 ± 108	2.81	5.97
Non-suppressive	32 ± 4.8	227 ± 149	3.44	5.25
*SED = 65.2			† SED = 0.346 † LSD = 0.75	

9



Fig. 9. Head region of a living *Macrobiotus* cf. *pseudohufelandi*. Photographed in the process of feeding on a nematode. Bright field optics showing mouth (m) and nematode (n). Scale bar = 10 μ m.

Wasser Bär). Three years later, Spallanzani (1776) (cited by Nelson & Higgins 1990) called them "slow steppers" or *Il Tardigrado* which gave rise to the phylum name used today. Because of their characteristic morphology, the tardigrades are recognized today as belonging to a discrete phylum. They probably evolved more than 500 million years ago in the Cambrian period when there was an explosive diversification of eukaryotic organisms. Although the Avon tardigrade clearly belongs to the *hufelandi* grouping in the genus *Macrobiotus* (Bertolani & Rebecchi 1993) its specific taxonomic identity is subject to further deliberation. This tardigrade has similar measurements to a population of *M. cf. pseudohufelandi* that includes specimens from WA (S. Claxton pers. comm.). Thus, despite the fact that they have "cooling tower"-shaped egg shell projections that are more like those illustrated for *M. hufelandi* (Nelson & Higgins 1990) than those illustrated for *M. pseudohufelandi* by Ramazzotti & Maucci (1983), which have much broader bases, they are tentatively assigned to *M. cf. pseudohufelandi* (S. Claxton pers. comm.).

The ability of tardigrades to survive in a wide range of environments and their world wide dispersal must be due in no small way to their ability to enter into an anhydrobiotic state, a function that they share with some nematodes and rotifers. I have shown that

M. cf. pseudohufelandi can survive for at least three years in dry soil maintained at room temperature. This was the maximum time tested and it seems likely that these creatures could survive for much longer under these conditions, since it has been reported (Keilin 1959) that survival times of up to 10 years can occur. Indeed, recovery, but not survival, has been reported to occur after 120 years of anhydrobiosis (Francheschi 1948 cited by Crowe 1971).

Anhydrobiosis is widespread in Phylum Tardigrada and it is thought that the disaccharide trehalose functions to protect these organisms since it accumulates within them as they are exposed to desiccation (Westh & Ramlov 1991). In this respect tardigrades resemble those nematodes that exhibit anhydrobiosis (Madin & Crowe 1975). In their morphology, of course, they are completely different and this is reflected in their different behaviour when observed in water under a coverslip. For example, *M. cf. pseudohufelandi* is able to push its way through an air bubble. This is a capability that I have never observed in a nematode.

The composition of the two sabre-shaped stylets does not appear to have been studied in detail and they are absent from camera lucida drawings because they break down and disappear in fixatives. Similarly, they break down on the natural death of the animals caused by anoxia on sealed slides. It seems strange that structures which, in the course of predation and feeding, can penetrate both plant and animal tissues, should be so fragile.

In the living state, the stylets are readily observed under all optical systems. However, when viewed under polarized light they exhibit marked birefringence indicating a regular structural orientation. It has been mentioned in the literature that the stylets are calcareous (Kaestner 1968) so their birefringence is probably crystalline and their break down under anoxic conditions might be due to an increased internal acidity leading to the dissolution of calcareous structures such as the stylets. Clearly such an hypothesis requires further testing.

Macrobiotus cf. *pseudohufelandi* was not observed to feed on the plant pathogenic fungus *Rhizoctonia solani* and I conclude that the tardigrade which I have found in large numbers in agricultural soils in South Australia probably does not feed on this fungus in the field but preys on other small soil organisms such as nematodes.

The ability of tardigrades to prey on nematodes has been recognized for some time. In 1969 Sayre showed that the tardigrade *Hypsibius myrops* could be cultured using the free-living nematode *Panagrellus redivivus* as prey (Sayre 1969). Furthermore, Sayre (1969) showed that *H. myrops*

was able to feed on the plant parasitic nematodes *Meloidogyne incognita* and *Ditylenchus dipsaci*. Sayre (1969) concluded that "under certain circumstances, (tardigrades may) give some control and these need to be investigated". A major drawback to this work was that it was conducted in a moist environment using moss as a substrate. This is a far cry from the normal environment of the plant parasitic nematodes that Sayre used in his experiments.

The tardigrade that I have reported upon in this paper comes from a true agricultural soil environment where it has to survive extremely harsh and variable conditions. Under these conditions, it may have the capacity to reduce nematode populations although the decline in the numbers of nematodes compared with the number of tardigrades may reflect the anhydrobiotic capabilities of the tardigrades compared with those of the mixed nematode population rather than predation by the

tardigrades. However, *M. cf. pseudohufelandi* may be an effective biocontrol agent, although little is known of its nematode food preferences and a more quantitative assessment of its potential for biocontrol of plant parasitic nematodes is needed.

Acknowledgments

I wish to thank Angela Reid CSIRO Biometrics Unit for the statistical analyses, Soils Division CSIRO for accommodation, facilities and expertise including that of Stuart McClure for the SEM and John Coppi for developing and printing the films. I thank Sandra Claxton for advice on tardigrade taxonomy and Jean Bird for constructive criticism of the manuscript. I am grateful for a grant from the Australian Biological Resources Study which provided facilities that made this research possible. I thank Robin Manley on whose farm the tardigrades were first discovered for his kind cooperation.

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RHOPALOMYIA GOODENIAE, A NEW SPECIES OF CECIDOMYIIDAE, (DIPTERA) DAMAGING GOODENIA LUNATA (GOODENIACEAE) IN INLAND AUSTRALIA

*BY PETER KOLESIK**

Summary

Kolesik, P. (1996) *Rhopalomyia goodeniae*, a new species of Cecidomyiidae (Diptera) damaging *Goodenia lunata* (Goodeniaceae) in inland Australia. Trans. R. Soc. S. Aust. 120(4), 155-160, 29 November, 1996.

A new gall midge species, *Rhopalomyia goodeniae*, is described from stem galls on *Goodenia lunata* (Goodeniaceae) from the Lake Eyre region, South Australia. Detailed descriptions of the larva, pupa, male, female and infestation symptoms are given. Plants infested by this gall midge are dwarfed and develop few or no flowers.

Key Words: Cecidomyiidae, *Rhopalomyia goodeniae* sp. nov., *Goodenia lunata*, Lake Eyre, South Australia.

RHOPALOMYIA GOODENIAE, A NEW SPECIES OF CECIDOMYIIDAE (DIPTERA) DAMAGING GOODENIA LUNATA (GOODENIACEAE) IN INLAND AUSTRALIA

by PETER KOLESIK*

Summary

KOLSIK, P. (1996) *Rhopalomyia goodeniae*, a new species of Cecidomyiidae (Diptera) damaging *Goodenia lunata* (Goodeniaceae) in inland Australia. *Trans. R. Soc. S. Aust.* 120(4), 155-160, 29 November 1996

A new gall midge species, *Rhopalomyia goodeniae*, is described from stem galls on *Goodenia lunata* (Goodeniaceae) from the Lake Eyre region, South Australia. Detailed descriptions of the larva, pupa, male, female and infestation symptoms are given. Plants infested by this gall midge are dwarfed and develop few or no flowers.

KEY WORDS. Cecidomyiidae, *Rhopalomyia goodeniae* sp. nov., *Goodenia lunata*, Lake Eyre, South Australia

Introduction

The insect family Cecidomyiidae is poorly known in Australia and until now, has been unrecorded from the inland regions of the continent. The species described here was found galling stems of *Goodenia lunata* J. Black (Goodeniaceae) in the vicinity of Lake Eyre South Australia in October, 1993.

Stiff (or hairy) goodenia, *Goodenia lunata*, is a perennial herb 5 - 20 cm high with 15 mm long yellow flowers. It grows in clay soils along watercourses and in sandy soils in central Australia. Flowering occurs throughout most of the year but peaks between September and November or after flooding or heavy rainfall (Cunningham *et al.* 1981; Cooke 1986).

The new gall midge species described below is placed in *Rhopalomyia*, a worldwide genus previously known in Australia from only one species, *R. californica* Felt, introduced to control *Baccharis halimifolia* (Asteraceae), an American ornamental plant turned pest on Australian pastures (McFayden *et al.* 1983; Gagné 1989a).

Materials and Methods

Plants of *Goodenia* sp. manifesting stem malformations caused by Cecidomyiidae larvae were collected at William Creek (50 km west of Lake Eyre), during a South Australian Museum collecting trip, on 22 October 1993. The few flowers produced by these plants shrunk in the course of drying precluding later authoritative identification of the species. New plants were sampled into 70% ethanol from the same population on 24 August 1995 and identified by D. E. Symon, State Herbarium of South Australia, as *G. lunata*. The galls collected on the

first occasion were processed in one of two ways. A small number was cut open and the larvae preserved in 70% ethanol. A larger number of galls was kept in plastic bags and the larvae were reared to adults. Pupation took place within the galls. Plastic bags were examined daily and emerged adults preserved together with their pupal skins in 70% ethanol. Canada balsam mounts of type specimens for microscopic examination were prepared according to the technique outlined by Kolesik (1995). The type series and other material retained in 70% ethanol are deposited in the South Australian Museum, Adelaide [SAMA] and the Australian National Insect Collection, Canberra [ANIC]. Dried and preserved (70% ethanol) samples of infested and uninfested plants are deposited in the State Herbarium of South Australia, Adelaide [SIHA].

Genus *Rhopalomyia* Rübsaamen, 1892

Rhopalomyia Rübsaamen, 1892: 370

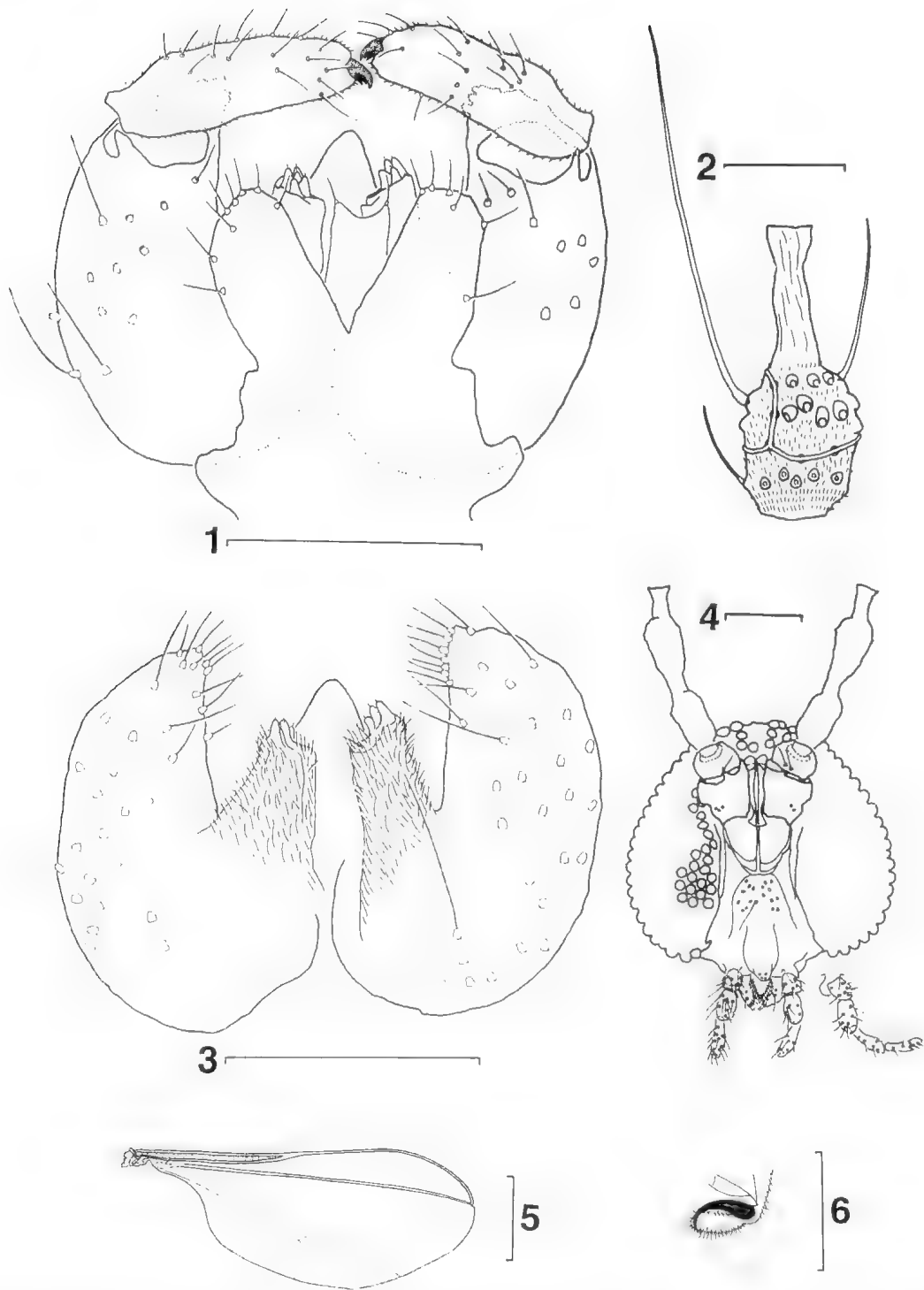
Type species: *Oligotrophus lanaceticola* Karsch, 1879: VII, Jber. westf. ProvVer. Wiss. Kunst: 27 (des Kieffer, 1896: 89)

Rhopalomyia is a worldwide genus comprising species of Oligotrophini with one- or two-segmented palpi, simple or toothed tarsal claws, elongate but entire eighth female abdominal tergite and completely setulose gonostylus. The species described here shares with *Rhopalomyia* all the above characters with the exception of having three- or four-segmented palpi. As the number of palpal segments is a derived character and varies within several Oligotrophini genera it does not preclude the new species from *Rhopalomyia*.

Rhopalomyia goodeniae sp. nov.
(FIGS 1-15)

Holotype: ♂, William Creek, South Australia [28°

* Department of Horticulture, Viticulture and Oenology, University of Adelaide PMB 1 Glen Osmond S. Aust. 5064.



Figs 1-6. Male of *Rhopalomyia goodeniae* sp. nov. 1. Genitalia in dorsal view. 2. Sixth flagellomere. 3. Gonocoxites, parameres and aedeagus in ventral view. 4. Head in frontal view. 5. Wing. 6. Tarsal claw with empodium. Scale bars = 100 μ m 1, 3, 4; 50 μ m 2, 6; 500 μ m 5.

55° S., 136° 20' E), 29.xi.1993, P. Kolesik, reared from larva from stem gall of *Goodenia lunata* J. Black, sampled 22.x.1993, I21328 [SAMA].

Paratypes: 2 ♂♂, 1 ♀, 2 pupal skins [SAMA], 1 ♂, 1 ♀, 2 pupal skins [ANIC], same data; 3 larvae [SAMA], 3 larvae [ANIC], collected with holotype.

Other material: 2 ♂♂, 1 ♀ [SAMA], same data; 35 larvae [SAMA], gall [SHSA - AD99511278], collected with holotype.

Description

Male (Figs 1-6)

Colour: sclerotized parts of body brown, non-sclerotized parts of abdomen orange. **Wing:** total length 2.7 mm (2.5 - 2.8, $n = 4$), width 1.0 mm (1.0 - 1.1); R5 at distal end narrower, more weakly sclerotized and slightly curved posteriorly, joining C anteriorly to apex; R1 joining C near wing mid-length; Sc cell strongly sclerotized and together with R1 and adjacent part of R5 bearing scales.

Flagellomeres 15 in number, first and second fused, with nodes longer than necks, third to fifteenth with nodes and necks about same length, circumfila comprising one transverse and one longitudinal band. **Palpus** four- or three-segmented with well developed palpiger in both cases. **Tarsal claw** simple, rounded beyond mid-length, empodia as long as claws.

Abdomen: all tergites with pair of setae in anterior corners, tergites I - VI with single setal row posteriorly and a few setae laterally, tergites VII and VIII with a few setae scattered in centre; sternites II - VIII with pair of setae anteriorly, row of setae posteriorly and fields of setae both laterally and centrally.

Genitalia: gonocoxites free ventrally, cylindrical, with small apicoventral lobe, setose and setulose; gonostylus situated dorso-caudally on gonocoxite, slightly tapering towards the apex, with apical tooth comprising strong claw and a few firm bristles, setose dorsally and setulose throughout; cerci bilobed, with several stout setae on each lobe, setulose; hypoproct bilobed, with seta on each lobe, setulose; parameres clasping aedeagus along their full length, setulose, apically bearing four to five large, setose papillae; aedeagus robust, conical.

Female (Figs 7-9, 11)

Wing: total length 1.9 mm (1.7 - 2.1, $n = 2$), width 0.8 mm (0.7 - 0.9); R5 straight and equally strong along full length as opposed to being narrower and curved posteriorly in male. **Tergite VII** with setal row posteriorly, **tergite VIII** with single pair of setae anteriorly, sclerotization of both tergites in shape of letter "Y". **Ovipositor** protrusible, cerci fused into

single, terminal lamella, triangular in dorso-ventral view, setose and setulose; hypoproct trapezoid in dorso-ventral view, bearing two setae posteriorly, setulose. Other characters as in male.

Pupa (Fig. 12)

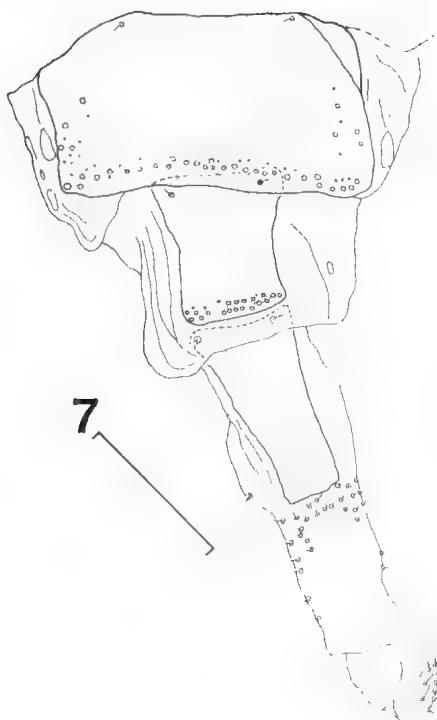
Colour: non-sclerotized parts of abdomen orange, the rest brown. **Total length** 2.7 mm (2.7 - 2.8, $n = 4$). **Integument** of abdominal segments covered with spiculae. **Cephalic sclerite** with two swellings as long as antennal horns, 30 μ m (25 - 36). **Cephalic pair of papillae** with strong setae, 148 μ m (143 - 152). **Frons** on each side, one of two lower facial papillae with seta and one of three lateral facial papillae with seta. **Prothoracic spiracle** 92 - 93 μ m in length, with trachea reaching its apex. **Abdominal segments I - VII** with pair of setose ventral papillae, two pairs of setose pleural papillae, pair of setose and two pairs of aetose dorsal papillae. **Abdominal segments II - VIII** dorsally with field of strong spines on anterior half. **Abdominal segments VIII and IX** with pair of setose ventral papillae, two pairs of setose pleural papillae and pair of setose dorsal papillae. **Facial papillae** with setae 5 - 6 μ m, papillae on abdominal segments with setae 5 - 8 μ m.

Larva (Figs 10, 13, 14)

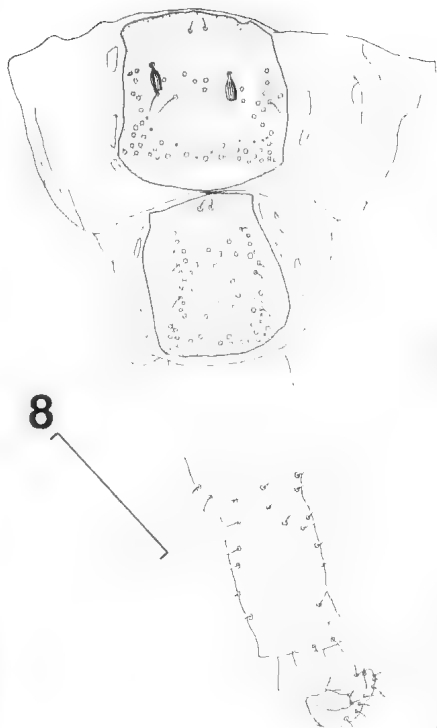
Colour: orange. **Total length** 3.0 mm (2.6 - 3.4, $n = 6$). **Integument** covered with dense spiculae, up to 10 μ m long. **Head** strongly sclerotized, 52 μ m (49 - 56) long and 88 μ m (85 - 91) wide, posterolateral apodemes 75 μ m (70 - 79) long, antennae 17 - 20 μ m long and 8 - 10 μ m wide at base. **Thoracic and first seven abdominal segments** with pair of ventral papillae, two pairs of pleural papillae and three pairs of dorsal papillae. **Thoracic segments** with pair of sternal papillae and two groups of three lateral papillae on each side of spatula, two of each with setae, one without. **Abdominal segment VIII** with two pairs of ventral papillae, two pairs of pleural papillae and pair of dorsal papillae, all with setae. **Abdominal segment IX** bearing four pairs of terminal papillae, all with setae, but some papillae lacking in some specimens. **Anus** ventral. **Setae** on sternal and lateral papillae about 1 μ m, on the other papillae 8 - 22 μ m. **Spatula** 294 μ m (245 - 328) long, with apical enlargement 132 μ m (116 - 150) in width and 44 μ m (34 - 48) in length.

Infestation symptoms (Fig. 15)

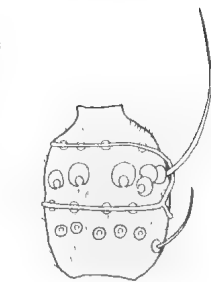
This gall midge species deforms the stems of *Goodenia lunata* into subglobular, hairy galls, 1-2 cm in diameter and 1-1.5 cm in height. Hairs are 1-2 mm long, dense, grey. The gall consists of many globular to subglobular, thick-walled cells with one larva in each cell. Infested plants develop few or no



7



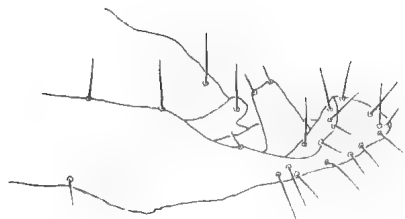
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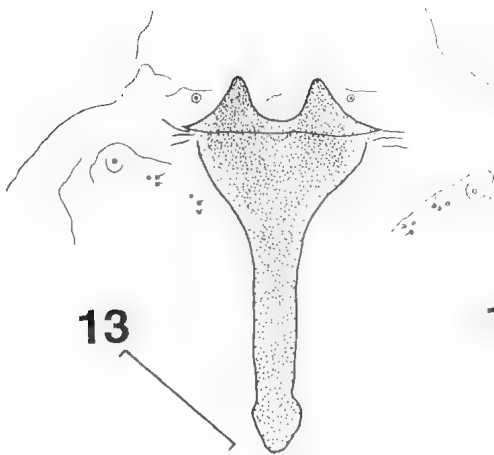
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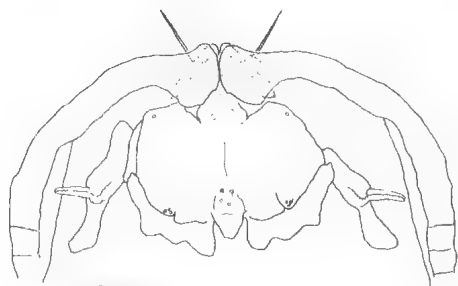
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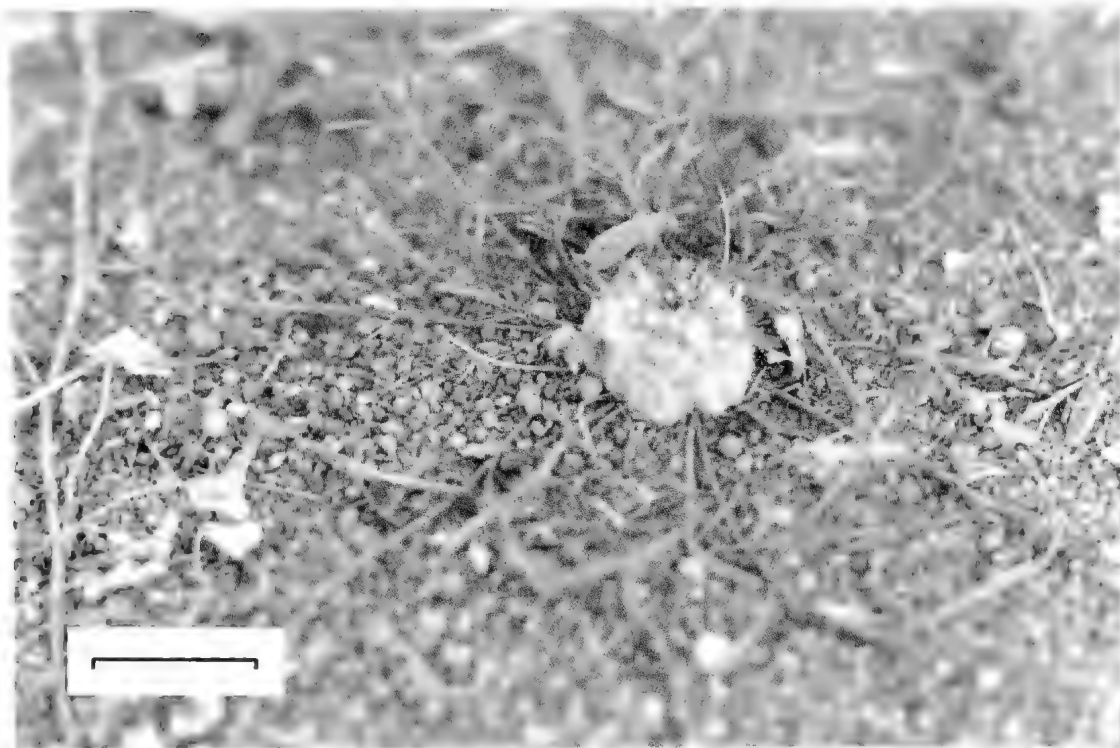


Fig. 15. Gall of *Rhopalomyia goodeniae* sp. nov. on *Goodenia lunata* J. Black. Scale bar = 20 mm.

flowers. On 22 October 1993 at William Creek, about 95% of all plants from a population comprising some 1000 plants were infested.

Etymology

Derived from the generic name of the host plant.

Discussion

Currently, the *Rhopalomyia* genus comprises 86 Nearectic (Gagné 1989b), 48 Palaearctic (Skuhravá 1986), 9 Neotropical (Gagné 1994) and 1 Oriental (Gagné 1973) species. No *Rhopalomyia* have been recorded from the Afrotropical Region (Harris 1980). Until now, only 2 immigrant species of *Rhopalomyia* have been recorded from Australasian and Oceanian Regions with *R. californica* having been introduced to Australia from North America

and *R. chrysanthemi* Ahlberg to the Hawaiian Islands and New Zealand from Europe (Gagné 1989a). *Rhopalomyia* is a catchall genus with the bulk of its species producing complex galls on Asteraceae. Species that form galls on other plant families exhibit some morphological differences and their placement in *Rhopalomyia* needs restudying (Gagné 1989b). The new species described here is the first native Australian species to be placed in *Rhopalomyia* and the only gall midge known to attack plants of the family Goodeniaceae. The species does not breach the current concept of *Rhopalomyia*, except that it has two or three palpal segments as opposed to one or two segments in other described members of the genus. Although this discrepancy precludes identifying the new species as *Rhopalomyia* using the most authoritative current key to Cecidomyiidae (Gagné 1981), I find it insufficient reason to erect a new genus until more is known about its native Australian congeners.

Figs 7-14. *Rhopalomyia goodeniae* sp. nov.: 7-9, 11 female, 10, 13, 14 larva, 12 pupa. 7. Posterior end of abdomen in dorsal view. 8. Posterior end of abdomen in ventral view. 9. Sixth flagellomere. 10. Head capsule in dorsal view. 11. Posterior end of ovipositor in lateral view (cerci shriveled in available specimen). 12. Anterior part in ventral view. 13. Sternal spatula with adjacent papillae. 14. Two terminal segments in dorsal view. Scale bars = 500 μ m 7, 8, 12; 50 μ m 9-11; 100 μ m 13, 14.

Rhopulomyia goodeniae sp. nov. differs in several characters from *R. californica*, its only Australian congener redescribed by Gagné & Boldt (1995). In *R. goodeniae*, the gonostylus is straight and about the same width throughout most of its length, the papillae on the male parameres are large (1/5 - 1/2 of paramere width), the number of palpal segments is three to four and the antennal horns in the pupa are minute and rounded. In contrast, *R. californica* has a gonostylus convex at the posterior end; papillae on the male parameres are minute (about 1/20 of paramere width), there are one to two palpal segments and the antennal horns in the pupa are elongate and bifid in frontal view.

Acknowledgments

I thank Ifeta and Philip Gee South Australian Outback Research William Creek for acting as guides in the Lake Eyre region and re-collecting the host plant specimens. I am grateful to Mark A. Adams and Terence B. Reardon Division of Natural Science South Australian Museum Adelaide for organizing and leading the collecting trip. David E. Symon State Herbarium of South Australia Adelaide courteously identified the host plant species. I thank John D. Gray Department of Horticulture, Viticulture and Oenology University of Adelaide and Raymond J. Gagné Systematic Entomology Laboratory USDA Washington DC USA for commenting on an early draft of the manuscript.

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**ROBUSTNEMA FOSTERI SP. NOV., GEN. NOV. (XYALIDAE,
MONHYSTERIDA, NEMATODA), A COMMON NEMATODE OF
MANGROVE MUDFLATS IN AUSTRALIA**

*By WARWICK L. NICHOLAS**

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A new genus with a single species, *Robustnema fosteri*, collected from mangrove mudflats is described. The circular amphids, six outer labial and six cephalic setae in one ring, annulated cuticle, single testis and single ovary with posterior vulva, place the genus in the Xyalidae. The buccal cavity is small, conical and unarmoured, the lips low and simple. The cardia and ovary are distinctive. Reproductive females are wide-bodied with a very large uterus filled with developing eggs and unhatched juveniles.

Key Words: Taxonomy, *Robustnema*, Xyalidae, Monhysterida, Nematoda, Mangrove.

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Introduction

A new species of nematode that is common in mangrove mudflats in south east Queensland and New South Wales is described. The possession of outer labial and cephalic sensillae in a single ring, circular amphids, an outstretched single gonad in both sexes, a posterior vulva, and an annulated cuticle place the new species in the Xyalidae (Monhysterida). It was previously misidentified as *Filipjeva* sp. (Hodda and Nicholas 1986; Nicholas *et al.* 1991) because of a resemblance to *P. crucis* Blome and Schrage 1985. However, more recent close inspection has shown that the reproductive organs are quite different and this nematode has been placed in a new genus.

Materials and Methods

Type specimens were collected at low tide from estuarine mud close to mangroves at Pine River Estuary, which opens into Moreton Bay north of Brisbane. Additional specimens have been collected from mangroves in New South Wales. Nematodes were fixed in the mud with 5% formalin immediately after collection and were recovered from the mud by a combination of sieving and centrifugation in aqueous colloidal silica (Ludox, Du Pont de Nemours) with specific gravity adjusted to 1.2. The mud was thoroughly dispersed in tap water, centrifuged at 6000 g for 7 minutes, the supernatant discarded, the residue re-suspended in colloidal silica, centrifuged again at 6000 g for 7 minutes, the supernatant passed through a nylon sieve with 60 µm

mesh, and nematodes retained by the filter back-washed into a petri dish. Specimens of the new species were picked up with an eyebrow hair (mounted on a stick) under a dissecting microscope and transferred to 5% aqueous glycerol. After the water had been allowed to evaporate at 40° C the nematodes were transferred to fresh anhydrous glycerol and mounted on slides with cover slips supported by glass beads (ballatum) and ringed with glyceel (Gurr).

Measurements, given in µm, were made from drawings of 12 specimens using a camera lucida. Type specimens are in The South Australian Museum (SAMA) and their numbers in the Australian Helminth Collection (AHC) are given.

***Robustnema* gen. nov.**

Six inner labial papillae, six outer labial setae and six cephalic setae in one ring; circular amphids. Six simple low lips, unarmoured buccal cavity, cuticle annulated. Cardia convex cap to anterior pair of intestinal cells. Single gonad in each sex, vulva close to anus, uterus becomes capacious sac holding developing eggs and juveniles.

***Robustnema fosteri* sp. nov.
(FIGS 1-9)**

Holotype: ♂, Pine River Estuary Queensland, 30.viii. 1986, SAMA AHC27695.

Measurements: Table 1.

Description of Holotype male

Typical nematode form (Fig. 3), curved ventrally in anal region, cuticle uniformly annulated. Tail proximally conical, posterior 20% narrow, almost cylindrical (Fig. 6). Body setae restricted to five

* Division of Botany and Zoology, Australian National University Canberra ACT 0200.

TABLE 1. *Measurements of Robustnema fosteri* sp. nov.

Sex Type	Holotype		Males Paratypes		Females Paratypes	
		Mean	SD	n=5 Range	Mean	n=6 Range
Length	1252	1242	29.28	1196-1273	1379	1089-1559
Max. width	71	68	2.80	65-71	114	71-161
Cephalic setae length	5.1	5.3	0.38	4.7-5.8	6.4	5.5-8.2
Amphid diam.	5.9	7.0	1.05	5.8-8.6	5.2	4.3-5.9
Buccal cavity width	10	11.4	0.55	11-12	12.5	10-14
Buccal cavity depth	14	18.8	2.39	16-20	17.8	14-20
Head to nerve ring	106	89	21.5	54-111	100	82-129
Pharynx length	212	224	19.4	200-254	238	192-268
Head to vulva					1098	805-1226
Head to anus	1040	1047	20.0	1018-1078	1164	905-1309
Tail length	226	197	18.1	185-226	206	184-226
Width at anus	57	56	5.27	49-62	68	59-77
Spicule, arc length	62	56	4.73	54-62		
De Man's a	17.6	18	0.680	17.6-19.6	12.5	9.0-15.3
" b	5.9	5.6	0.374	5.0-6.0	5.8	4.9-6.7
" c	5.5	6.3	0.463	6.1-6.7	6.7	5.9-7.5
" e*	4.0	3.5	0.420	3.0-4.1	3.1	2.6-3.8
" V %					79	74-85

paired, ventral setae, evenly spaced between anus and tail tip, 4 μ m long, plus three terminal 4 μ m long setae. Six stout lips arched over buccal cavity forming shallow dome arising from very short parallel-sided region, demarcated from cervical region by strong annular groove (Fig. 1). Six minute inner labial papillae on lips; six short outer labial and six equally short slightly wider cephalic setae inserted side by side at base of lips; amphids circular, situated at level of buccal cavity. Buccal cavity small, simple, conical, without teeth, cuticular ridges or denticles. Pharynx cylindrical without muscular bulb, cardia with about 12 small cells forming convex cap to anterior pair of intestinal cells (Fig. 4). No renette cell, 'excretory' duct or pore. Intestinal cells large, paired, with prominent nuclei and granular cytoplasm, rectum very short, about 30 μ m long. Testis single, outstretched, to left of intestine, extending anteriorly almost to cardia, long seminal vesicle filled with rounded spermatozoa, extending posteriorly a little beyond mid-body, long vas deferens, very short ejaculatory duct (Fig. 3). Short strong spicules, arc length 62 μ m (Fig. 7), with capitulum, shallow angular bend half-way along, extreme tip forms narrow peg; gubernaculum two slightly curved rods; two very small papilliform pre-anal supplements, 46 and 77 μ m anterior to anus (Fig. 6). Three post-anal caudal glands.

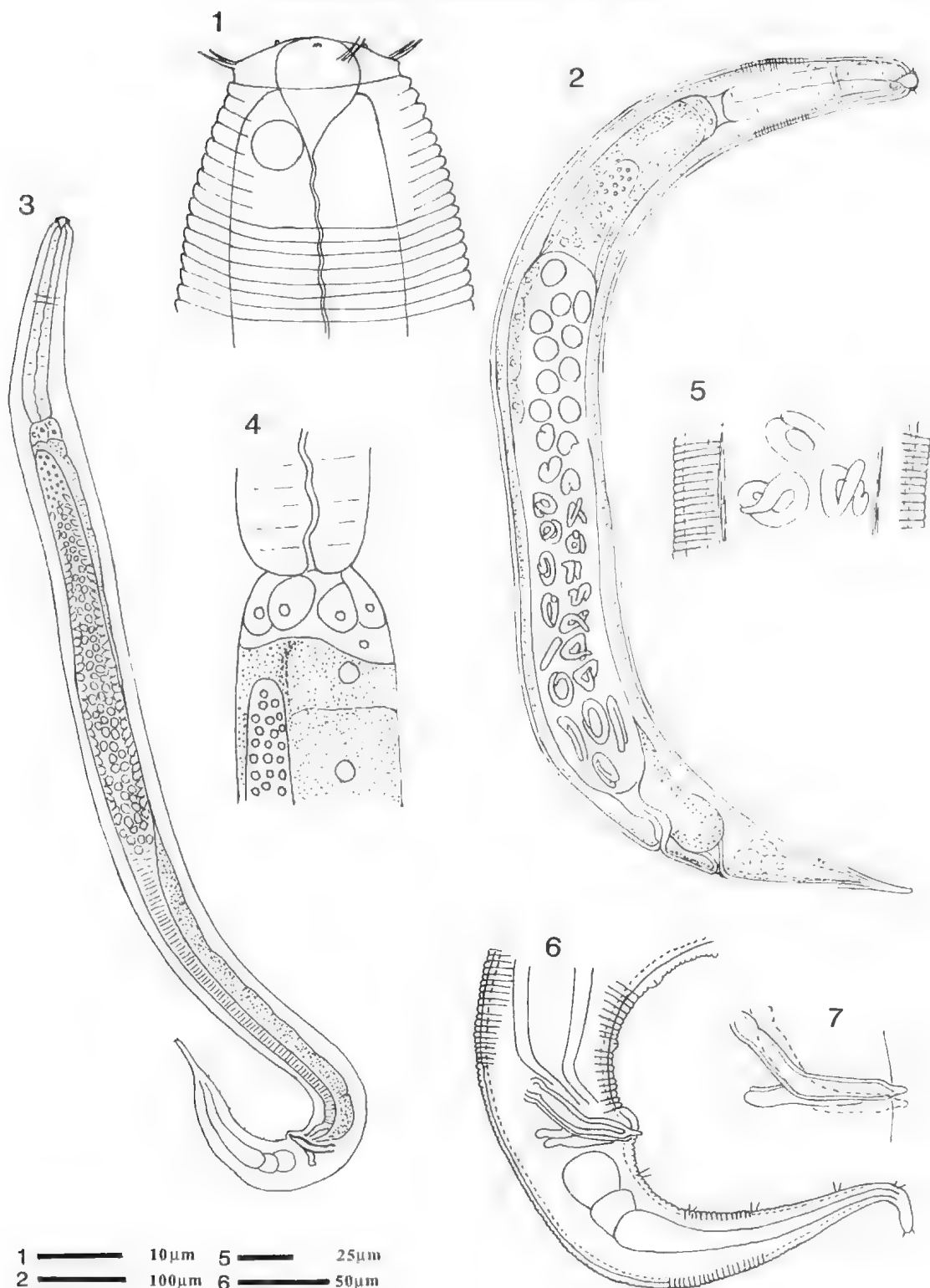
Paratypes: From Pine River Estuary Queensland, 30.viii. 1986, SAMA AHC27660- 27663.

Measurements: Table 1.

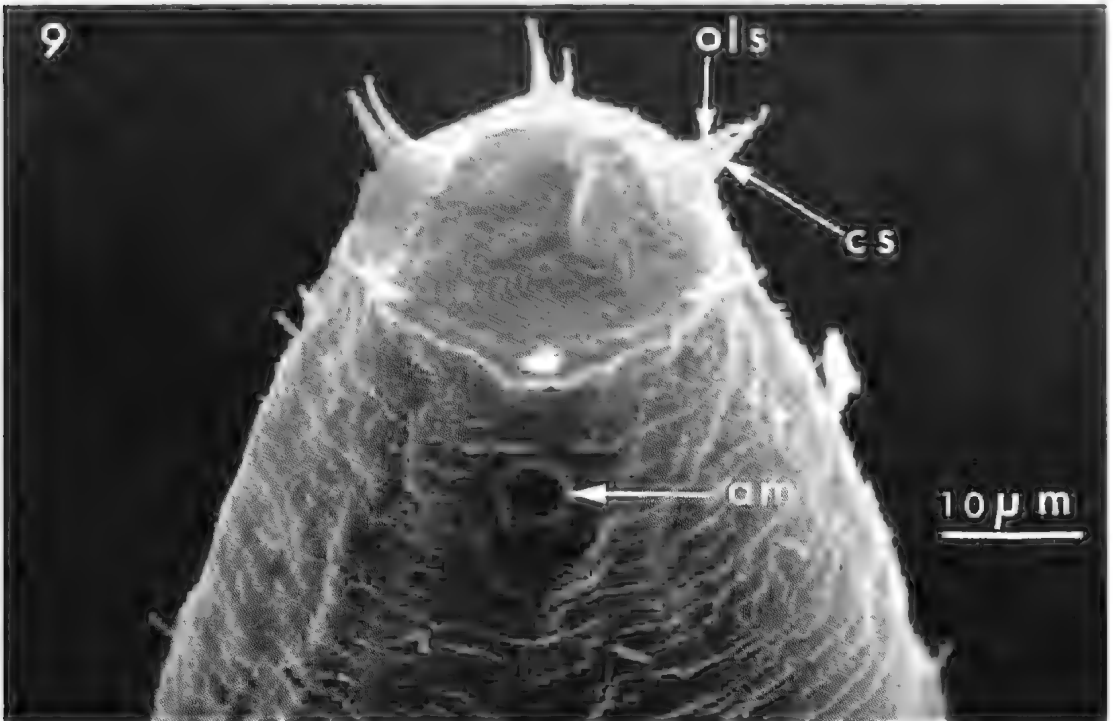
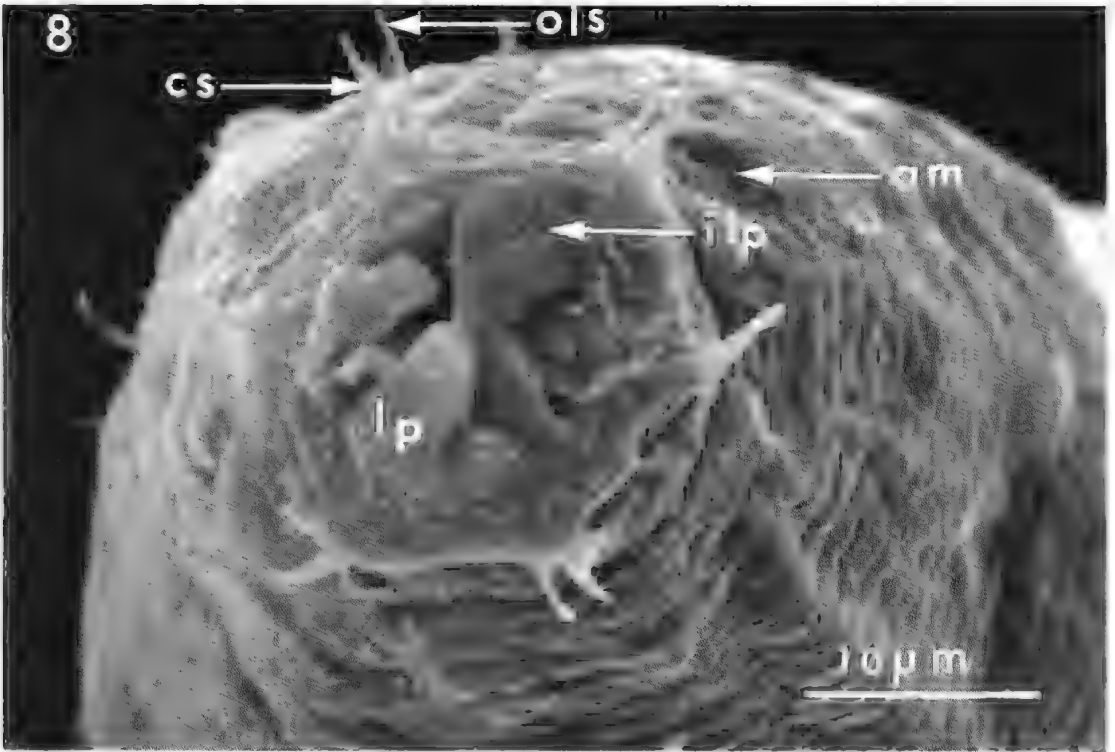
Five σ δ essentially similar to holotype. The tip of the tail is not necessarily bent dorsally as it is in the holotype. Pre-anal supplements very difficult to find in some males when they do not protrude in profile. Five σ σ of much stouter build than males, but not all arched dorsally as in paratype illustrated in Fig. 2. Uterus forms a large thin-walled sac occupying more than half the body length. The uterus is filled with developing eggs anteriorly and fully-formed unhatched juveniles posteriorly (Fig. 5). There may be as many as 28 juveniles and embryonated eggs. The egg shell is not rigid and it accommodates the shapes of the developing embryos, which are about 30-40 μ m long. Juveniles, curled within the thin flexible shell are 150-200 μ m long. Three to six granular cells, probably unfertilised oocytes, lie along the anterior dorsal wall of the uterus.

Scanning electron microscopy (Figs 8, 9) confirms that there are six cephalic setae, inserted beside the corresponding outer labial setae. The cephalic setae are wider at their bases than the outer labial setae. Figures 8 and 9 show that the six lips are deeply incised and that the head is hexagonal when viewed *en face*.

Figs. 1-7. *Robustnema fosteri* sp. nov. 1. Male head. 2. Gravid female. 3. Entire male. 4. Cardia. 5. Small portion of annulated cuticle and uterus containing unhatched juveniles. 6. Male tail, spicules, caudal glands, setae and pre-anal supplements. 7. Spicules and gubernaculum. 1, 4, 6 and 7 holotype male; 2, 3, and 5 paratype male and female AHC27661



1	10 μ m	5	25 μ m
2	100 μ m	6	50 μ m
3	100 μ m	7	25 μ m
4	10 μ m		



Figs. 8-9. Scanning electron micrographs of head of *Robustinema fosteri* sp. nov. ols outer labial seta. cs cephalic seta. am anuphrid. ilp inner labial papilla. lp lip

Differential diagnosis

The presence of six cephalic setae in the second ring of sensilla, while not unique, is unusual in Xyalidae as is the small size of the unarmoured buccal cavity and low profile of the lips. The shape of the cardia and ovarian development are quite distinctive within the Xyalidae. Together these characters justify generic status.

Habitat

Mangrove mudflats.

Distribution

Pine River estuary, opening into Moreton Bay Queensland; Fullerton Cove opening to the Hunter River estuary New South Wales and the Clyde River estuary New South Wales.

Etymology

Generic name from the strongly built body, especially the very stout-bodied reproductive female; specific name after a colleague.

Discussion

The female reproductive system is unusual and its development warrants further study. Only a discontinuous developmental series has been observed. In immature females, the outstretched ovary is filled with small cells, presumably oogonia. After fertilisation, large eggs in early cleavage stages appear amongst the small cells. By this time the ovary extends forwards almost to the level of the cardia. Later the ovary is largely transformed into a capacious uterus filled with developing eggs and, towards the posterior, unhatched juveniles. Some large granular cells, with single nuclei, lie along the dorsal wall of the uterus. These large cells are probably unfertilised oocytes and ovarian development can be described as hologonic rather than showing the much more usual telogonic development. No spermatozoa were recognised within the female gonad.

Acknowledgments

I am grateful to The Australian Biological Resources Study for travelling expenses.

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**A REDESCRIPTION OF ASPERSENTIS ZANCHLORHYNCHI
(JOHNSTON & BEST, 1937) COMB. NOV.
(HETERACANTHOCEPHALIDAE:ACANTHOCEPHALA)**

*BY LESLEY R. SMALES**

Summary

Smales, L. R. (1996) A redescription of *Aspersentis zanchlorhynchi* (Johnston & Best, 1937) comb. nov. (Heteracanthocephalidae: Acanthocephala) Trans. R. Soc. S. Aust. 120(4), 167-171, 29 November, 1996.

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Key Words: Acanthocephala, *Aspersentis*, Antarctic, fish hosts.

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KEY WORDS: Acanthocephala, *Aspersentis*, Antarctic, fish hosts

Introduction

Acanthocephalan material, collected by the Australasian Antarctic Expedition (AAE) of 1911-1914, was the subject of a report by Johnston & Best (1937). In that report they described a new species, *Echinorhynchus zanchlorhynchii*, occurring in the stomach of a scorpaenid fish, *Zanchlorhynchus spinifer* Günther, from Macquarie Island. Since their description was based on a single female with its proboscis not fully everted, Johnston & Best (1937) indicated that the examination of additional specimens would be required to confirm the species, its description and its taxonomic position.

Subsequently, two immature specimens (one male, one female) were found in *Z. spinifer* collected at Macquarie Island during the British Australian and New Zealand Antarctic Research Expedition (BANZARE) of 1929-31, and identified as *A. zanchlorhynchii* by Edmonds (1957).

More acanthocephalans were found when members of the Australian National Antarctic Research Expeditions (ANARE) of 1986 - 1990 collected *Z. spinifer* from Macquarie and Heard Islands. Examination of this material has allowed a more complete description of the acanthocephalan to be prepared. These specimens, whilst conforming to the general descriptions of Johnston & Best (1937) and Edmonds (1957) had asymmetrical proboscis armature and spines on the trunk, features characteristic of the *Aspersentinae*. The significance of these morphological data are considered in this paper and an analysis of the current status of the genus *Aspersentis* is given.

Materials and Methods.

Thirteen *Zanchlorhynchus spinifer* collected from Macquarie Island waters (54° 33' S, 158° 53' E) and one from the Heard Island shelf (trawled between 51° 34' and 53° 30' S, 72° and 78° 00' E) were fixed in 10% formalin buffered with excess sodium tetraborate. Fish were then examined under a dissecting microscope and any acanthocephalans found were stored in 70% ethanol prior to examination, either as temporary wet mounts, after clearing in beechwood creosote, or as permanent preparations, after staining in Grenacher's carmine alum, dehydrating through a graded series of ethanol, clearing in xylene and mounting in Canada balsam.

Measurements of 10 males and 10 females were made with the aid of an ocular micrometer, drawing tube and measuring wheel and are given in μ m unless otherwise stated, with the range followed by the mean in parentheses. Figures were drawn with the aid of a drawing tube. All specimens have been deposited in the Queensland Museum (QM).

Systematics

Order Palaeacanthocephala Meyer, 1931

Family Heteracanthocephalidae Petrochenko, 1956

Subfamily Aspersentinae Golvan, 1960

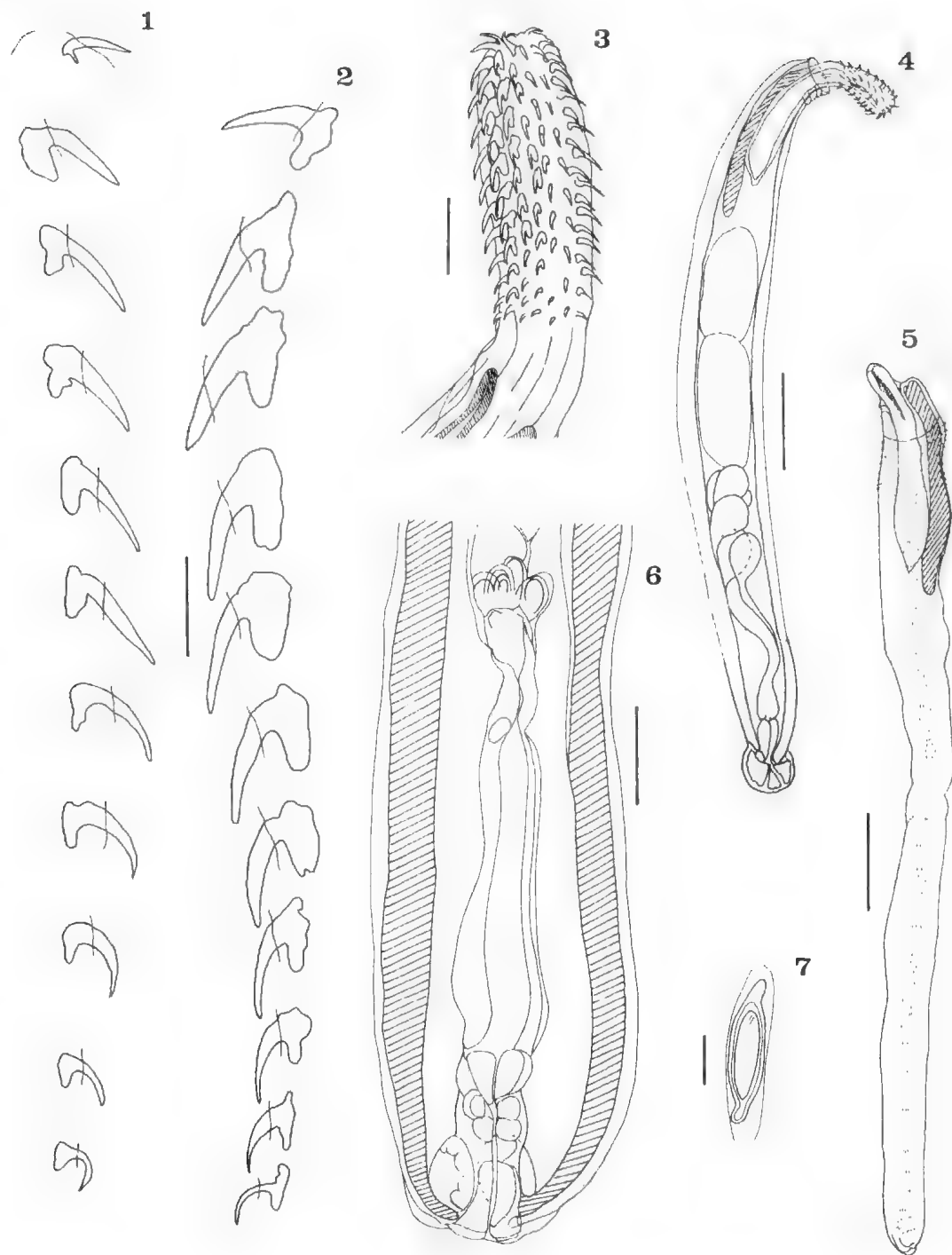
Genus *Aspersentis* van Cleave, 1929

Type species *Aspersentis austrinus* Van Cleave, 1929.

Aspersentis zanchlorhynchii (Johnston & Best, 1937) comb. nov.
(FIGS 1-7)

Synonym *Echinorhynchus zanchlorhynchii* Johnston & Best, 1937 pp. 12-13; Edmonds, 1957 p. 96, *E.s.l. zanchlorhynchii* Zdzitowiecki, 1986 pp. 89, 102, table 1.

* University of Central Queensland, Rockhampton Qld 4702.



Figs 1-7 *Aspersentis zunchlorhynchi* comb. nov. Fig. 1. Proboscis armature, one row of dorsal hooks. Fig. 2. Proboscis armature, one row of ventral hooks. Fig. 3. Proboscis, dorsal view. Fig. 4. Male. Fig. 5. Female, proboscis not fully everted, showing distribution of trunk armature. Fig. 6. Posterior end, female. Fig. 7. Egg. Scale bars = 50 μ m, 1, 2: 150 μ m, 3: 100 μ m, 6: 500 μ m, 4, 5: 25 μ m, 7.

Material examined

From *Zanchlorhynchus spinifer*: 126 ♀♀, 170 ♂♂, Macquarie Island, 6.ii.86, 12.vi.86, 6.xii.86; G211324-G211335, 1♀ Heard Island, 11.vi.90; G211323.

Revised description

Trunk cylindrical. Proboscis long, cylindrical, set at angle to trunk (Figs 4, 5). Proboscis armature similar in both sexes, 14-16 rows of 10-12 hooks (Fig. 3); dorsal rows of hooks (Fig. 1) somewhat smaller than ventral rows (Fig. 2); all hooks with roots. Neck short unarmed, truncated. Spines tiny, embedded in cuticle in both sexes, encircling anterior end of trunk to a level about halfway down proboscis receptacle, then extending down lateral trunk to posterior (Fig. 5). Proboscis receptacle double-walled, inserted at base of proboscis; ganglion placed near posterior end. Lemnisci flat, longer than proboscis receptacle when fully extended.

Male: Trunk 3.4-6 (4.2) mm long by 360-680 (480) wide. Proboscis, not fully extended in most specimens, 650 long by 215 wide ($n=1$). Largest dorsal hooks 3rd and 4th in row, 53-63, largest ventral hooks 3rd and 4th in row 76-85. Neck 130-195 (145) long by 140-260 (175) wide. Proboscis receptacle 615-995 (735) long. Lemnisci 740-1300 (930) long. Testes ovoid, tandemly placed; anterior testis 455-985 (675) long by 180-300 (265) wide, posterior testis 490-715 (635) long by 195-445 (280) wide. Cement glands, six, pear-shaped. Male aperture terminal.

Female: Trunk 5.3-16 (10) mm long by 390-765 (500) wide. Proboscis, not fully extended, longer than 900, width 200. Largest dorsal hooks, 3rd and 4th in row, 50-56; largest ventral hooks, 3rd and 4th

in row 80-83. Neck 182-227 (200) long by 175-260 (205) wide. Proboscis receptacle 810-1300 (1160) long; lemnisci 925-1940 long ($n=2$). Female aperture terminal (Fig. 6). Eggs embryonated, with prolongations of middle shell 75-90 (87) long by 18 wide (Fig. 7).

Host: *Zanchlorhynchus spinifer* Günther.

Location: stomach, intestine.

Locality: Macquarie Island.

Type specimens: Holotype female, South Australian Museum V 2200.

Remarks

Although a large number of specimens was collected, none of them had been relaxed and extended prior to fixation, which made them difficult to study. Comparison of the material from this study with the descriptions of Johnston & Best (1937) and Edmonds (1957) showed that all the material collected from *Z. spinifer* was the same species. In many specimens the lemnisci were as described by Johnston & Best (1937) that is, short and irregular and reaching about one-third the length of the proboscis receptacle but in the more relaxed specimens, the lemnisci were flat and extended beyond the proboscis receptacle. The cylindrical shape of the proboscis and its armature, 14-16 rows of 10-12 hooks, were observed in the three specimens described by Johnston & Best (1937) and Edmonds (1957) but in none of them had the proboscis extended far enough to describe the morphological details of the proboscis hooks. The asymmetry of the armature, ventral hooks being larger than dorsal ones, could be seen only in those

TABLE 1. A comparison of female body measurements of *Aspersentis australis* Van Cleave, 1929 (taken from Zditowleckl 1981), *A. minor* Edmonds & Smiles, 1992 and *A. zanchlorhynchi* (Johnston & Best, 1937). Measurements in mm.

	<i>A. australis</i>		<i>A. minor</i>	<i>A. zanchlorhynchi</i>
	South Shetlands	South Georgia	Tasmania	Macquarie & Heard Is.
trunk length	4.93-6.42 (5.79)	6.94-8.54 (7.25)	2.3-4.1 (3.2)	5.3-16.0 (10.0)
trunk width	1.16-1.79 (1.39)	1.09-2.09 (1.73)	0.31-0.95 (0.54)	0.39-0.76 (0.50)
proboscis length	0.51-0.66 (0.59)	0.67-0.73 (0.70)	0.24-0.32 (0.28)	>0.90
proboscis width	0.29-0.32 (0.30)	0.29-0.35 (0.32)	0.10-0.17 (0.14)	0.20
dorsal hook length (maximum)	0.054-0.064 (0.060)	0.060-0.060 (0.062)	0.030-0.035 (0.032)	0.050-0.056
ventral hook length (maximum)	0.119-0.137 (0.126)	0.132-0.149 (0.140)	0.062-0.080 (0.065)	0.080-0.083
neck length	0.17-0.23 (0.126)	0.22-0.31 (0.27)	0.12-0.25	0.18-0.23 (0.20)
egg	0.060-0.088	0.071-0.087	0.068-0.077	0.075-0.090 (0.087)
	\bar{x} 0.019-0.025	\bar{x} 0.020-0.025	\bar{x} 0.012-0.016	\bar{x} 0.018
hook disposition	13-16 rows of 7-11 hooks/row		14 rows of 7-9 hooks/row	14-16 rows of 10-12 hooks/row

specimens with the proboscis almost, or completely, everted. This character is indicative of the genus *Aspersentis* rather than the genus *Echinorhynchus* to which the species was originally allotted. Somatic armature, present in this species, is also found on other species of *Aspersentis* (see Zdzitowiecki 1981, 1986) but not *Echinorhynchus*. Since tiny spines are easily overlooked, as has occurred in some collections of *A. austrinus* (see Zdzitowiecki and Rokosz 1986), it is not surprising that they were undetected in the earlier studies.

Aspersentis zanchlorhynchi (Johnston & Best, 1937) comb. nov. can be distinguished from *A. austrinus* Van Cleave, 1929 in having a more cylindrical trunk, a longer proboscis, at least 650 in males and 900 in females, compared with up to 630 in males and 720 in females, in the distribution of trunk spination on the lateral trunk as well as encircling the anterior trunk, and less marked asymmetry of the proboscis armature with both ventral and dorsal hooks having roots. *Aspersentis zanchlorhynchi* has more hooks per row (10-12) than does *A. austrinus* (7-11) on the proboscis (Table 1).

In comparison with *A. minor* Edmonds & Smales, 1992, females 3.2 mm, and *A. johnei* (Baylis, 1929) Chandler, 1934, females 3.0 mm, *A. zanchlorhynchi* is much larger, females 10 mm. With 10-12 hooks per row on the proboscis, *A. zanchlorhynchi* has more hooks than *A. minor*, 7-9, and fewer hooks than *A. johnei*, 12-14. *Aspersentis minor* occurs in *Rhombosolea tapirina* from Tasmanian waters (Edmonds & Smales 1992) and *A. johnei* occurs in *Merluccius* sp. around the Falkland Islands (Yamaguti 1963). By contrast *A. zanchlorhynchi* occurs in *Z. spinifer* from Macquarie and Heard Islands, that is from sub-Antarctic and Antarctic waters.

Discussion

In a redescription of *A. austrinus* Zdzitowiecki (1981) placed *Rhadinorhynchus wheeleri* Baylis, 1929, *Aspersentis wheeleri* Chandler, 1934 and *Aspersentis megarhynchus* (Linstow, 1892) Golvan, 1960 nec *Echinorhynchus megarhynchus* Linstow, 1892 as synonyms of *A. austrinus*. He commented that Linstow (1892) gave the number of proboscis hook rows as 18 and described the trunk as unarmed and that Linstow neither measured, described nor drew the ventral and dorsal rows of hooks as having different shapes and dimensions. All of these characters are inconsistent with the genus *Aspersentis*. Amin (1985), however, in his classification of the Acanthocephala overlooked Zdzitowiecki's paper and followed Golvan (1960) in

listing *A. megarhynchus* (Linstow, 1892) with *A. austrinus* as its synonym and *A. johnei* (Baylis 1929) as the only two valid species in the genus.

Zdzitowiecki & Rokosz (1986) re-evaluated the validity of *Heteracanthocephalus hureaui* Dollfus, 1965 and concluded that it was either a synonym of *A. austrinus* or, because of the wide range of number of hooks per row, of *A. johnei*. Zdzitowiecki (1986) in his systematic review of Antarctic acanthocephalans reaffirmed his conclusion that *Echinorhynchus megarhynchus* Linstow, 1892 did not belong in the genus *Aspersentis*, and listed *H. hureaui* as a synonym of *A. austrinus*. Then Zdzitowiecki (1990), when re-examining material previously designated *H. hureaui*, stated that, "as was suggested earlier *H. hureaui* is identical with *A. austrinus* = *A. megarhynchus*". Edmonds & Smales (1992) noted the inconsistencies in the designation of *A. austrinus* by Zdzitowiecki (1981, 1986, 1987, 1990) and indicated that *E. megarhynchus* as described by Linstow (1892) lacked body spines and did not have asymmetric proboscis hooks.

Thus, *A. megarhynchus* as redescribed by Golvan (1960), is not the same species as *E. megarhynchus* Linstow, 1892 because it has asymmetric proboscis armature and cuticular spines on the trunk, and is now considered as *A. austrinus*. Since *A. austrinus* was described in 1929 by Van Cleave while *A. megarhynchus* was not established until 1960 by Golvan, *A. austrinus* becomes the type species of the genus *Aspersentis* with *A. megarhynchus* as a synonym. The other synonyms are *A. wheeleri* (Baylis, 1929), *Rhadinorhynchus wheeleri* (Baylis, 1929) and *Heteracanthocephalus hureaui* (Dollfus, 1965).

The genus *Aspersentis* therefore now consists of four valid species *A. austrinus*, *A. johnei*, *A. minor* and *A. zanchlorhynchi*.

As to *Echinorhynchus megarhynchus*, Johnston & Best (1937) suggested that it might be identical to *Leptorhynchoides debenhamsi* (Lieper & Atkinson, 1914) Johnston & Best, 1937 now *Metacanthocephalus rennecki* (Lieper & Atkinson, 1914) Zdzitowiecki, 1983. *Echinorhynchus megarhynchus* occurs in *Notothenia coriiceps*, one of the hosts of *Metacanthocephalus johnstoni* Zdzitowiecki, 1983, but not in *Trematomus bernachii* the host of *M. rennecki* (see Zdzitowiecki 1983). Moreover the original description of *E. megarhynchus* by Linstow (1892) resembles that of *M. johnstoni* in having a proboscis armature of 18 rows each of 6 hooks, the proboscis 0.45 mm long, and apparently no neck. Of the other species occurring in Antarctic fish hosts, *Echinorhynchus petroschenkoii* (Rodjuk, 1984) Zdzitowiecki, 1989, is a larger helminth than *E. megarhynchus* with a longer proboscis, proboscis armature of 15-19 rows

of 10-13 hooks, and does not occur in *N. coriiceps* (see Zdzitowiecki 1989). *Heterosentis heteracanthus* (Linstow, 1896) has body spines and proboscis armature of only 10 rows of 4-5 hooks, with a striking difference between the length of the first two and the last three hooks (Zdzitowiecki 1984). These characters suggest that *E. megarhynchus* is closer to *M. johnstoni* than any of the other acanthocephalan species occurring in Antarctic fish. Direct

examination of specimens of *M. johnstoni* is needed before a determination on the status of *E. megarhynchus* can be made.

Acknowledgments

My thanks to Dr R. Williams who collected the parasites and Professor K. Rohde who made them available.

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SEASONAL ACTIVITY OF THE EARTHWORM, GEMASCOLEX LATERALIS (MEGASCOLECIDAE), IN A EUCALYPTUS WOODLAND IN SOUTH AUSTRALIA

BRIEF COMMUNICATION

Summary

The earthworm fauna of agricultural habitats, especially pastures, has been extensively surveyed in south-eastern Australia in recent years^{1,4}. The fauna is dominated by accidentally introduced species, particularly Lumbricidae from Europe (e.g., *Aporrectodea caliginosa*, *A. trapezoides* and *A. rosea*). Native species are rare. Very little is known of the biologies of native earthworms, either in urban, agricultural or native habitats^{3,5-11}. This brief communication reports on the seasonal activity of *Gemascolex lateralis* (Spencer 1892) (Megascolecidae), one of the most common native species in South Australia, and offers one possible explanation for its rarity in pastures.

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The earthworm fauna of agricultural habitats, especially pastures, has been extensively surveyed in south-eastern Australia in recent years¹⁻⁴. The fauna is dominated by accidentally introduced species, particularly Lumbricidae from Europe (e.g., *Aporrectodea caliginosa*, *A. trapezoides* and *A. rosea*). Native species are rare. Very little is known of the biology of native earthworms, either in urban, agricultural or native habitats⁵⁻¹¹. This brief communication reports on the seasonal activity of *Gemascolex lateralis* (Spencer 1892) (Megascolecidae), one of the most common native species in South Australia, and offers one possible explanation for its rarity in pastures.

Engelbrook National Trust Reserve is an open forest (*Eucalyptus obliqua* - *E. baxteri*) at Bridgewater in the Mount Lofty Ranges, SA (350 m altitude. Grid reference 962224 on Sheet 6627-1, Echunga, 1 : 50000). The

understorey of the reserve is composed of shrubs such as *Banksia*, *Acacia*, *Hakea*, *Leptospermum* and *Hibbertia* spp. The soil is a yellow podzolic. Average annual rainfall is 1050 mm. Much of Engelbrook Reserve has been burnt by bushfires in recent years but the sites reported here had not been burnt for at least 35 years at the time of the study.

Baker^{12,13} set eighty pitfall traps (plastic jars, 9 cm diam., 9 cm deep) flush with the soil surface within Engelbrook Reserve in March 1983. Forty traps were set on a north-west slope and the other forty on a south-west slope. The traps were set 10 m apart in two transects on each slope. Each trap was covered by a ceramic tile (15 x 15 cm), set approximately 2 cm above the traps on three nails. These tiles prevented rain and leaf litter from fouling the traps. No preservative was added to the traps. The traps were inspected weekly until March 1984 and the invertebrates

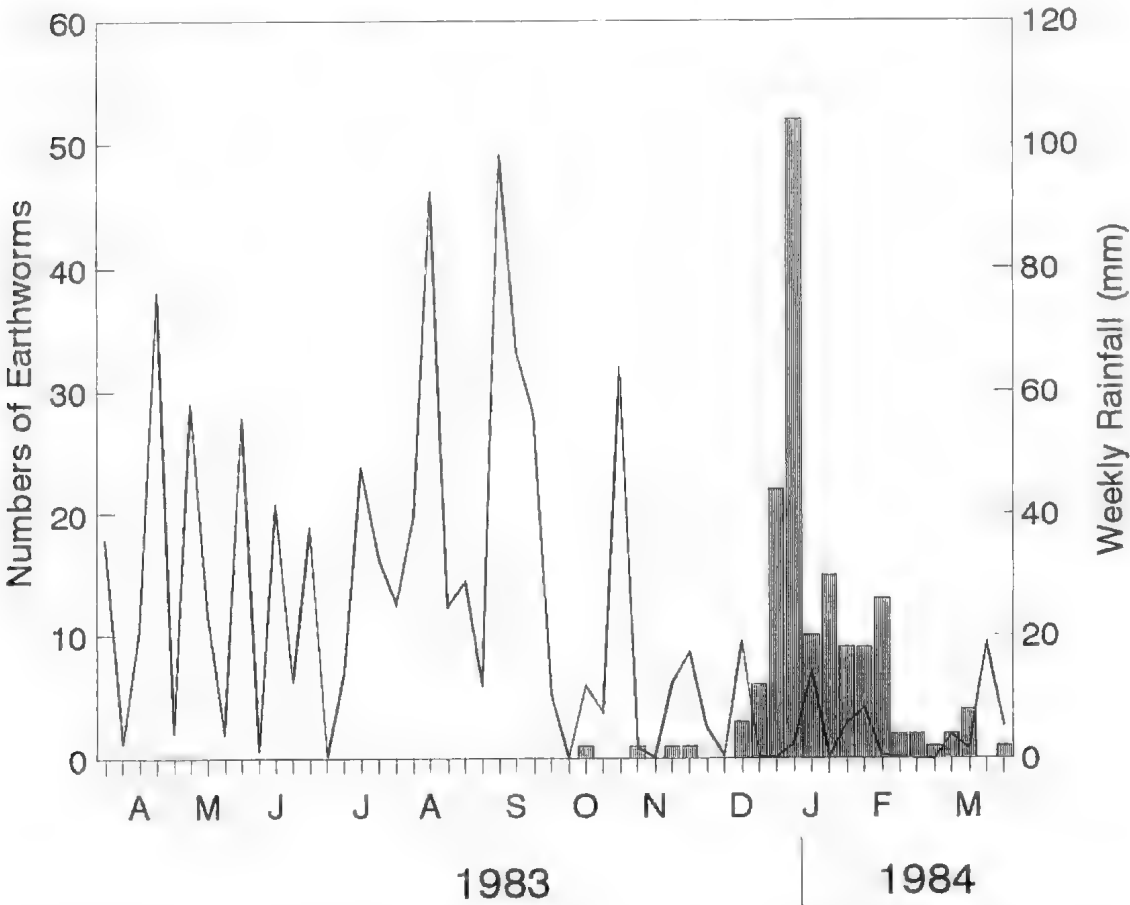


Fig. 1. Numbers of *Gemascolex lateralis* trapped per week in Engelbrook Reserve, SA during 1983-84 (bars). Weekly rainfalls, recorded nearby at Stirling Post Office, are included (line).

that were caught were preserved for later counting.

One species of earthworm, *G. lateralis*, was trapped, mostly in the summer months (Fig. 1). There was no discernible difference between the catches on the two slopes ($t = 1.42$, $p > 0.05$ for a paired t test comparing total weekly catches for the two slopes). The data for the two groups of traps have therefore been combined in Fig. 1. There was no apparent relationship between the peak in trapped earthworms in December and prevailing weather (e.g., rainfall) at that time ($r = -0.239$, $p > 0.05$ for weekly data for 9 November 1983 to 21 March 1984).

The activities of earthworms, on and near the soil surface, are usually associated with cool, wet weather in temperate and mediterranean habitats^{14,15}. In particular, Abbott¹ reported that the activity of native earthworms in a jarrah forest in south-western WA was restricted to winter and spring when soil moisture was highest. It is therefore surprising that the surface activity of *G. lateralis* peaked in summer at Engelbrook Reserve when weather was at its hottest and driest. However, Lawson¹⁰ found *G. lateralis* throughout the year in the surface layers of the soil (0–5 cm deep) in a *Eucalyptus* woodland near Cape Jervis, SA. She argued that, because of the predominance of clitellate adults

at this time, *G. lateralis* reproduced during the hotter, warmer months of the year in this woodland. She did not find cocoons (at any time) to verify this conclusion. In addition, Lawson could not find *G. lateralis* in a nearby pasture. Baker *et al.*⁹ did find small numbers of *G. lateralis* in other pastures in the Mount Lofty Ranges. In these pastures, *G. lateralis* was present in the top 10 cm of soil from autumn to spring but retreated to greater depths in the summer months. Most worms were found in a patch within one pasture near a clump of *Eucalyptus* trees and fallen logs.

Why *G. lateralis* is present, indeed most active, on the soil surface in native woodlands during summer is not at all clear. Apparently, the shelter provided by the above-ground vegetation in woodlands provides sufficient moisture and cool temperatures to enable such behaviour. But in open pastures, it seems likely that the lack of similar vegetation would prevent this summer surface activity and hence reduce the abundance of *G. lateralis*. If it is to survive in pastures at all through summer, *G. lateralis* must retreat from surface layers to greater depths where conditions are cooler and moister, as do the more abundant, introduced lumbricids^{12,16}.

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GASTRO-INTESTINAL PARASITES OF FERAL CATS IN THE NORTHERN TERRITORY

BRIEF COMMUNICATION

Summary

The feral cat, *Felis catus*, is well established as a predator in Australia and feeds on insects, fish, amphibians, birds, reptiles and native and introduced mammals¹. Several surveys of the gastro-intestinal parasites of feral cats have been carried out in south-eastern Australia^{2,3,4,5}, the species and prevalence of the parasites encountered varying between states, depending on available food sources and climate. In this study we present information on the gastro-intestinal parasites recovered from feral cats collected from the Northern Territory, a region from which only limited data currently exist.

BRIEF COMMUNICATION

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The feral cat, *Felis catus*, is well established as a predator in Australia and feeds on insects, fish, amphibians, birds, reptiles and native and introduced mammals.¹ Several surveys of the gastro-intestinal parasites of feral cats have been carried out in south-eastern Australia^{2,3,4}, the species and prevalence of the parasites encountered varying between states, depending on available food sources and climate. In this study we present information on the gastro-intestinal parasites recovered from feral cats collected from the Northern Territory, a region from which only limited data currently exist.

Staff from the Parks and Wildlife Commission of the Northern Territory trapped and/or shot 188 feral cats for this study between 1991 and 1993. Twenty-two cats originated from Watarrka (Kings Canyon) National Park south-west of Alice Springs (24° 20' and 25° 20' S, 130° 50' to 132° 45' E), 25 from an area north of the MacDonnell Ranges from Glen Helen Gorge to Yambah and Alcolola Stations (22° 50' to 23° 45' S, 133° 30' to 134° 55' E), 45 near Mount Davidson in the Tanami Desert Wildlife Sanctuary, north-west of Alice Springs (20° 20' to 20° 55' S, 130° 25' to 131° 55' E), 8 in the Davenport Ranges from Murray Downs Station via Barrow Creek (20° 50' to 21° 00' S, 134° 10' to 134° 25' E), 51 from Lake Nash (Mparurulan) (20° 20' to 21° 10' S, 137° 50' to 138° 10' E) on the Barkly Tablelands, 18 from the northern Barkly Tablelands (17° 50' to 19° 45' S, 134° 00' to 137° 00' E) and 19 from Marrakai to Katherine (12° 35' to 14° 30' S, 131° 20' to 142° 20' E) south-east of Darwin.

The stomachs of the cats were opened so that undigested contents could be identified and then the entire gastro-intestinal tracts were preserved in 10% formalin or 70% ethanol. The preserved material was transported to Adelaide

where parasites were removed and counted using a dissecting microscope and later, after they had been cleared in lactophenol, identified employing a compound microscope. When present, rectal samples were examined for protozoa using centrifugal flotation in saturated MgSO₄ solution.

Many of the helminths found (Table 1) have been reported previously in surveys of feral cats from New South Wales, Victoria and Tasmania (*Ancylostoma tubaeforme*, *Cyathostomum dissonis*, *Toxocara canis*, *Sprometra erinacei*, *faenia taeniaciformis*) although there are significant differences in prevalence between states. The principal difference between this survey and previous ones is the very low prevalence of *T. cati* in the Northern Territory. Only 9.0% of the cats examined had no parasites.

Acanthocephalan parasites occurring in feral cat populations elsewhere have been referred to as *Onchicola* sp.^{2,3,4}. Schmidt⁵ identified the species as *Onchicola pomatostomi*. Both the dingi, *Canis familiaris dingi*, and feral cat act as definitive hosts, with larval stages occurring under the skin of a variety of passerine birds. *Onchicola pomatostomi* was the most commonly detected parasite in this study and was also present in large numbers in many of the cats. Although worms were found with their probosces deeply embedded into the intestinal mucosa, the associated pathological reactions were limited to an inflammatory infiltrate around the probosces, detected when histological sections were examined. This parasite was not recovered from 19 cats in the area south of Darwin but was present in animals from all arid areas of the Northern Territory. The large numbers of *O. pomatostomi* found in cats suggests that birds constitute a significant item of their diet, although a lack of data on abundance of this parasite in paratenic hosts prevents more detailed conclusions from being drawn.

Physaloptera praeputialis and *Abbreviata hastaspicula* have been reported from feral cats and dogs from the Northern Territory¹ on a single occasion. The evidence here confirms that *P. praeputialis* is a relatively common parasite of feral cats in central Australia. *Abbreviata hastaspicula* is normally a parasite of varanid lizards⁶ but, apparently, will develop also in the stomach of cats. Ryan² found a '*Physaloptera*' sp. present in cats in New South Wales but at that time dismissed it as an incidental parasite. It may have been *A. hastaspicula* but the lack of deposited specimens makes it impossible to confirm this hypothesis.

Ancylostoma tubaeforme is generally considered to be the common hookworm of domestic cats⁷ but records to date suggest that it is uncommon in feral cats except in those collected in the vicinity of Sydney². *A. tubaeforme* was widely distributed in the Northern Territory, occurring most frequently in cats from the Kings Canyon area, the MacDonnell Ranges and Murray Downs Station. Infections consisted of small numbers of worms (maximum number = 31). A single cat was found infected with *A. caninum*, a parasite more commonly found in canids in Northern Australia¹; this cat harboured only five adult worms.

An immature specimen of *Gnathostoma spinigerum* was

TABLE 1. Prevalence of intestinal helminth parasites found in 188 feral cats from the Northern Territory.

Parasite	Prevalence (%)	Abundance (mean)
Acanthocephala		
<i>Onchicola pomatostomi</i>	65.4	1-999 (130)
Nematoda		
<i>Abbreviata hastaspicula</i>	4.3	1-46 (12)
<i>Ancylostoma caninum</i>	0.5	5
<i>Ancylostoma tubaeforme</i>	12.8	1-31 (4)
<i>Cyathostomum dissonis</i>	4.3	1-13 (5)
<i>Physaloptera praeputialis</i>	40.4	1-51 (8)
<i>Toxocara cati</i>	1.0	3-15 (9)
Cestoda		
<i>Sprometra erinacea</i>	14.4	1-25 (6)
<i>Faenia taeniaciformis</i>	47.9	1-79 (7)

found in the stomach of a cat collected in Kings Canyon. *G. spinigerum* has been found sporadically in feral cats in Australia¹² but appears to be uncommon.

The identity of *Taenia taeniaeformis* was confirmed by counting and measuring the large and small rostellar hooks from 13 cestode scoleces and comparing the data with those provided by Verster¹⁰. *Spinimetra erinacei* was detected in all of the cats collected in the area to the south of Darwin but in only eight cats from the other areas of the Northern Territory. This may be due to the fact that the first intermediate host of this parasite is a fresh-water crustacean of the genus *Cyclops*¹¹ and the pools of fresh water necessary for its transmission are less frequent in arid areas. Parasites such as *Dipylidium caninum*, *Uncinaria stenocephala* and *Cylicospirum felinus*, present in other surveys, were not found.

Faecal examinations revealed two species of coccidia, *Isospora felis* in 9.6% of 146 cats and *I. rivolta* in 6.9%. Both are common parasites of cats and can cause disease in younger animals. The majority of the cats examined were adults and this could explain the low prevalence of coccidian infections (including the absence of *Toxoplasma gondii*) in this and other surveys⁴.

Additional nematodes, *Echinonema cinctum*, *Rictularia costarici* and *Wuarterstrongylus stenoti* were rarely found and their presence was presumably the result of the ingestion of native mammals and reptiles which are the normal hosts of these parasites. Similarly, the ingestion of birds would explain the presence of female nematodes of *Apocata* sp. in the stomachs of two cats. Other parasites

collected from intestinal contents and faeces but obviously related to the ingestion of rodent hosts were *Demodex* sp. and *Psorergates* sp. *Xenopsylla vexabilis*, a flea found commonly on *Rattus villosissimus* was found in the stomach of cats from the Lake Nash area and the mite, *Laelaps hupuloti*, a parasite of *Notomys* spp., was found in cats from the Tanami Desert area. Another accidental parasite recovered was *Syplacia obvelata* an oxyurid parasite in the caecum of rodents.

The information presented here identifies a greater variety of parasites occurring in feral cats in the Northern Territory than previous studies have found. It identifies *P. praeputialis* as a common parasite and demonstrates that cats are frequently infected with *A. hastaspicula*. It also confirms that the feral cat preys on native mammals, birds and reptiles. This is particularly so in the case of birds, with the large numbers of *O. pomastomi* suggesting frequent predation.

This work was begun by Murray Barton, when employed at the Arid Zone Research Institute, Alice Springs and was conducted on material collected by the staff of the Conservation Commission of the Northern Territory, Alice Springs. We wish to thank Mr Barton and all of the individual officers who kindly collected and preserved the viscera of the cats and David Gibson for his help with the manuscript.

Representative specimens of all of the helminths collected have been deposited with the Australian Helminthological Collection, South Australian Museum. Registration numbers AHC 30181 to 30231.

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**PREDATION OF EARTHWORMS BY THE LAND PLANARIAN,
AUSTRALOPLANA SANGUINEA (MOSELEY) VAR. ALBA
(DENDY) SENSU JONES, 1981 (TRICLADIDA: GEOPLANIDAE)**

BRIEF COMMUNICATION

Summary

Earthworms can significantly reduce soil degradation and improve pasture and crop production¹. Land planarians (terrestrial flatworms) can, however, greatly reduce the abundance of earthworms in agricultural fields. For example, a New Zealand planarian, *Artioposthia triangulata* (Dendy), has been accidentally introduced into the British Isles where it now feeds voraciously on local earthworm populations. The implications for crop and pasture yields and the abundance of wildlife that feed on earthworms in the British Isles, are of major concern^{2,3,4}. Another planarian, *Australoplana sanguinea* (Moseley) var. *alba* (Dendy) sensu Jones, 1981, has also been accidentally introduced to the British Isles, either from Australia or New Zealand^{2,5,6}. Relatively little is known of its biology, in particular its feeding habits, except that it will feed on “earthworms”.

BRIEF COMMUNICATION

PREDATION OF EARTHWORMS BY THE LAND PLANARIAN, *AUSTRALOPLANA SANGUINEA* (MOSELEY) VAR. *ALBA* (DENDY) SENSU JONES, 1981 (TRICLADIDA: GEOPLANIDAE)

Earthworms can significantly reduce soil degradation and improve pasture and crop production¹. Land planarians (terrestrial flatworms) can, however, greatly reduce the abundance of earthworms in agricultural fields. For example, a New Zealand planarian, *Arthropostha triangularis* (Dendy), has been accidentally introduced into the British Isles, where it now feeds voraciously on local earthworm populations. The implications for crop and pasture yields and the abundance of wildlife that feed on earthworms in the British Isles, are of major concern^{2,3}. Another planarian, *Australoplana sanguinea* (Moseley) var. *alba* (Dendy) sensu Jones, 1981, has also been accidentally introduced to the British Isles, either from Australia or New Zealand^{2,3}. Relatively little is known of its biology, in particular its feeding habits, except that it will feed on 'earthworms'⁴.

Australoplana species are widespread and frequently encountered in man-modified habitats in eastern Australia⁵. Recently, *A. sanguinea* var. *alba* has been found to be neither *A. sanguinea* nor *A. alba* but is in fact a new genus and species (L. Winsor, pers. comm.). This flatworm's only known occurrence in Australia is at Kingswood, South Australia, although it probably occurs in other urban and disturbed habitats.

The dorsal surface of *A. sanguinea* var. *alba* is mostly a uniform pale orange-brown colour with a deeper brown-peach anterior tip; its ventral surface is white. *A. sanguinea* var. *alba* was commonly found by one of us (T.E.T.) in moist habitats, such as under bricks, rocks and pieces of wood and, sometimes, in the top 10 cm of soil in a suburban garden in Kingswood. It fed on garden earthworms when offered them in plastic jars, but not on other invertebrates such as snails, slugs, millipedes, slaters or earwigs.

This paper documents five earthworm species upon which *A. sanguinea* var. *alba* will feed under laboratory conditions and provides some data on its reproduction and early development. The work forms part of a broader study aimed at improved management of earthworms as a resource in south-eastern Australia⁶.

Firstly, six adult *A. sanguinea* var. *alba* (approx. 6.8-cm long) were collected from the Kingswood garden in October 1994. These planarians were placed in pairs in three opaque, closed plastic containers (diam. 9 cm; height 10 cm) and maintained at 15°C. The bottom of each container was covered with 1.5 cm of garden soil which was kept moist by spraying regularly with water. Five exotic earthworm species, *Aporrectodea caliginosa* (Savigny), *A. niseni* (Savigny), *A. trapezoides* (Duges) and *A. longa* (Ode) (Lumbricidae) and *Microcolex dubius* (Fletcher) (Acanthodrilidae) were offered to the planarians as food. These earthworm species, apart from *A. longa* which is widespread in and was obtained from northern Tasmania, are commonly found in gardens and agricultural fields in South Australia and Victoria^{7,8}. Two individuals of a particular earthworm species were introduced into each

container with the flatworms; one earthworm species at a time. Predation was assessed over a period of 31 d. Earthworm species were changed in the containers when predation occurred. All species of earthworm were killed and eaten by *A. sanguinea* var. *alba*. The planarians ate all or part of an earthworm. All parts of the body were attacked, namely head, tail and midsection. In some cases, where only the tail was eaten, the earthworm survived. In contrast, earthworms always die when partially eaten by *A. triangularis*.

Secondly, seven adult *A. sanguinea* var. *alba*, from the same Kingswood garden, were placed in separate plastic containers, as described above. Two adult *Aporrectodea caliginosa* were added to each container. The numbers of missing or partially eaten earthworms were recorded approximately every 24 h for 36 d. Earthworms were replaced if complete or partial predation had occurred. Two planarians died during the experiment, both at day 28. On average, earthworms were attacked once every 5 d per planarian (range 1-12 d). This is similar to the rate at which *A. triangularis* attacked another earthworm species, *Eisenia fetida* (Savigny) (1.4 attacks per planarian per week at 10°C)⁹.

During the first experiment, the six planarians deposited five egg capsules between them. In the second experiment, the seven planarians deposited 17 egg capsules (4, 4, 0, 1, 2, 3 and 3 each). The capsules were spherical to oval in shape and ranged from 3-4 mm in diameter. They were maroon-red in colour and were deposited either on the soil surface or a few mm below it but were not attached to the soil surface by slime as has been noted by Ferráze & Baker¹⁰ for *Ctenophora caerulea* (Moseley). The egg capsules were maintained at 15°C in opaque, closed plastic containers (diam. 7 cm; height 5 cm) for up to 149 d. Fourteen of the capsules hatched. These successful capsules were deposited between 31 October and 13 December 1994 and all hatched during February 1995. Mean hatching time was 87 d (range 71-101 d). Forty-one juvenile planarians were reared from the capsules, 1-5 from each capsule (mean = 5). Upon emergence, these juveniles were pale yellow in colour with a reddish anterior tip. The main body colour darkened to either a grey or pale orange-brown over a 3-11 d period. The juvenile planarians were provided with juvenile *A. caliginosa* as food (*ad lib.*) and began feeding on them after an average of 10 d (range 3-22 d). Height of the juvenile planarians reached adult size three months after emergence. These eight individuals were then grouped in one container, and, after a further month, produced three egg capsules between them.

Introduced lumbricid earthworms are generally much more abundant than native species in urban and agricultural soils in southern Australia¹¹. Native earthworms are presumed to be more abundant in undisturbed habitats, where invasion by introduced species is believed to be limited^{12,13,14}. Whether or not *A. sanguinea* var. *alba* preys

upon native earthworm species or significantly influences the abundance of either introduced or native species in disturbed or undisturbed sites in the field has yet to be determined. However, given the numbers of earthworms eaten in the laboratory experiments (1 worm / planarian / 5

d), the influence of *A. sanguinea* on earthworm abundance could be significant.

We thank Don Terrace for help with the collection of the planarians and Leigh Winsor for assistance with identifications.

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T. E. TERRACE, Division of Soils and G. H. BAKER, Division of Entomology, CSIRO PMB 2 Glen Osmond S. Aust. 5064.

MASS FROG MORTALITY AT TWO LOCALITIES IN SOUTH AUSTRALIA

BRIEF COMMUNICATION

Summary

In recent years much attention has been given to the alarming decline in amphibian populations worldwide. Australia is no exception to this with severe reductions in population size recorded for several species^{1,2,3}. Suggested reasons for apparent declines vary widely, with habitat alteration and fragmentation, acid rain, introduction of exotic animals, toxicants, increased UV and pathogens being implicated in several instances^{4,5,6}. It is possible that such factors also act in concert⁵. For example, habitat alteration may sufficiently stress the frogs so that their immune systems become compromised, making them more susceptible to infection⁷. It has also been suggested that such declines may only be a small part of a naturally occurring cycle of population flux⁸.

BRIEF COMMUNICATION

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In recent years much attention has been given to the alarming decline in amphibian populations worldwide. Australia is no exception to this with severe reductions in population size recorded for several species^{1,2}. Suggested reasons for apparent declines vary widely, with habitat alteration and fragmentation, acid rain, introduction of exotic animals, toxicants, increased UV and pathogens being implicated in several instances^{3,4,5,6}. It is possible that such factors also act in concert⁷. For example, habitat alteration may sufficiently stress the frogs so that their immune systems become compromised, making them more susceptible to infection⁸. It has also been suggested that such declines may only be a small part of a naturally occurring cycle of population flux⁹.

In the field the observation of several dead frogs simultaneously is unusual as they degrade quickly after death. Hence the presence of multiple carcasses is a sign of mass mortality in a short time frame (for frogs this would probably be less than three days). There have been recent reports of such a phenomenon from several regions including Switzerland¹, Hawaii¹⁰, England⁷ and Australia. Here we report mass frog mortalities at two localities in South Australia.

The first incident took place on 20 May 1992. Rain at Nuriootpa, South Australia (latitude 34° 29' S, longitude 139° 01' E) filled a dam on a vineyard to a depth of approximately 0.5 m. Numerous burrowing frogs (*Neobatrachus pictus*) emerged and, on the following day, many were found dead at the edges of the dam. One of us (M.J.T.) visited the site on 23 May 1992 and recovered 32 dead specimens. All were at the edge of the water which had already receded to a depth of 0.3 m. Some had laid spawn but other dead, gravid individuals were located. The spawn had dried out and it could not be determined if the ova had been fertilised.

The simultaneous nature of the death of the frogs indicated the presence of a pollutant. According to the landowners the only chemical used at the site was spot spraying of the herbicide Roundup (manufactured by Monsanto, and consisting of glyphosate and a dispersant) to control thistles. Spraying had been undertaken approximately three months previously (in February 1992). This period should have been adequate for the degradation of the herbicide.

The second site of mass mortality was at Paralana Hot Springs, 27 km north-east of Arkaroola Homestead in the northern Flinders Ranges (UM 499606 on Yundnamulana 6737, 1:50000 topographic map). This is a geothermally heated body of water through which radon gas bubbles. Water emerges at 60° C and has a radioactivity of approximately 2000 pCi/l. After sufficient rainfall fresh water can also be found upstream of the hot spring. On 9 December 1994 nine dead frogs were discovered by C.W. floating at the hot source of the spring and, by their state, were considered to have been dead for less than two days. Seven (including one juvenile) were the spotted grass frog, *Limnodynastes tasmaniensis*, and the other two were representatives of the red tree frog, *Litoria rubella*. Their advanced state of decay precluded a meaningful investigation by pathologists.

Despite extensive searches, no living *Limnodynastes tasmaniensis* were discovered at the site, whereas *Litoria rubella* was heard calling but not seen. In cooler parts of the spring downstream, there were both larval and adult frogs (Crimia riparia) and no dead frogs were found. These observations were made the day after the first occasion that rain had fallen for one month.

Mass mortalities were again recorded on 8 May 1996 at the same site. Eleven dead *C. riparia* were found both at the hot source and upstream of it in isolated pools of cooler water (23° C). These included both adults and juveniles. Several living larval, juvenile and adult *C. riparia* and *L. tasmaniensis* were also observed at the site on this date. Occasional sightings of dead frogs floating in the hot pools have been made regularly over the last 20 years (D. Sprigg pers. comm.).

The presence of such a large number of dead frogs is suggestive of a pathogenic cause. This occurrence cannot be attributed readily to any form of anthropogenic interference, and while high water temperature may have contributed to the mass mortality, it is unlikely to have been the single cause of so many deaths within such a short time. Although investigation into amphibian pathogens is still in its infancy they have been previously linked with frog mortalities both in Australia¹¹ and abroad¹².

Simon Steinborner, Adrian Bradford, Steven Walker and Rebecca Short are thanked for their assistance in the field.

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